Holistic Environmental Assessment of Oil and Gas Field Development

by

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TABLE OF CONTENTS

ABBREVIATIONS

ACBE	Advisory Committee on Business and the Environment
AFEN	Atlantic Frontier Environmental Network
ALARP	As Low As Reasonably Practicable
AS	Absolute Standard
ASMS	Affordable Safe Minimum Standard
BAT	Best Available Technique
BMA	British Medical Association
BOD	Biological Oxygen Demand
BPEO	Best Practicable Environmental Option
CALM	Catenary Anchor Legged Moored
CBA	Cost Benefit Assessment
CBC	chlorobromocarbon
CFC	chlorofluorocarbon
CGS	Concrete Gravity Structure
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CVM	Contingent Valuation Method
DETR	Department of the Environment, Transport and the Regions
DTI	Department of Trade and Industry
E&P	exploration and production
EA	Environmental Assessment
EC	European Community
EDV	Environmental Damage Valuation
EEC	European Economic Community
EIA	Environmental Impact Assessment
EMAS	Eco-Management and Audit Scheme
EMS	Environmental Management System
EOSCA	European Oilfield Speciality Chemicals Association
EPA	Environmental Protection Agency (US)
ERMSA	Environmental Risk Mitigation System Analysis
ERT	Environment and Resource Technology
ES	Environmental Statement
EU	European Union
FPSO	Floating Production Storage and Offloading
FRS	Fisheries Research Services
FSO	Floating Storage and Offloading
GBS	Gravity Based Structure
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Pollution
GWP	Global Warming Potential
HCFC	hydrochlorofluorocarbon
HEA	Holistic Environmental Assessment
HM	Her Majesty's
HOCNF	Harmonised Offshore Chemical Notification Format
HSE	Health and Safety Executive
HSEM	Health Safety and Environment Management
IEA	*former* Institute of Environmental Assessment
IEMA	Institute of Environmental Management and Assessment
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
IPIECA	International Petroleum Industry Environmental Conservation Association
IRR	Internal Rate of Return
ISO	International Standard Order
IVM	Indirect Valuation Method
JNCC	Joint Nature Conservation Committee
LAO	linear alpha olefin

LCA	Life-Cycle Analysis
LCERMA	Life Cycle Environmental Risk Mitigation Analysis
LPG	liquefied petroleum gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MCA	Marine and Coastguard Agency
MSF	Module Support Frame
NAMEA	National Accounting Matrix including Environmental Accounts
NO_x	nitrogen oxides
NPV	Net Present Value
NWECS	Northwestern European Continental Shelf
OBM	oil-based mud
OCNS	Offshore Chemical Notification Scheme
OPRC	Oil Pollution Preparedness Response and Co-operation
OSPAR	Oslo and Paris Convention
OSPARCOM	Oslo and Paris Commission
PAH	polycyclic aromatic hydrocarbon
PARCOM	Paris Commission
PFC	perfluorocarbon
PM_{10}	Particulates
PON	Petroleum Operation Notice
QSR	Quality Status Report
RCEP	Royal Commission on Environmental Pollution
REIA	Regional Environmental Impact Assessment
SAC	Special Area of Conservation
SBM	synthetic-based mud
SEA	Strategic Environmental Assessment
SEBA	Workgroup on Sea-based Activities
SO_2	sulphur dioxide
SPA	Special Protection Area
SSCV	Semi-Submersible Crane Vessel
SWOPS	Single Well Offloading System
TERA	Total Environmental Risk Assessment
TLP	Tension Leg Platform
UKCS	UK Continental Shelf
UKDMAP	UK Digital Marine Atlas Project
UKOOA	UK Offshore Operators Association
UNEP	United Nations Environmental Programme
VLSSCV	Very Large Semi-Submersible Crane Vessel
VOC	volatile organic compound
WBM	water-based mud
WCED	World Commission on Environment and Development
WTA	willing-to-accept
WTP	willing-to-pay

LIST OF TABLES

LIST OF ILLUSTRATIVE MATERIAL

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The author would like to take this opportunity to acknowledge the many contributions that have helped at all stages of this study. The most important figure has been my supervisor John Ford whose foresight initiated the project, and whose critical reviews and support kept me on track. Our meetings to discuss environmental issues and their interaction with engineering have been an invaluable learning experience. In addition I would like to acknowledge the assistance and encouragement from Andrew Tweedie, Paul Kingston, Tony Booer, Robert Laws, Lars Sonneland, Jon Side, David Pearce, Robert Ramage, Sam Subbey, Anthony King and Graeme Ardus.

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The completion of a PhD that assesses man's impact on the environment has been a burning ambition of mine ever since I worked on the Great Barrier Reef for the Australian Institute of Marine Science and Great Barrier Reef Marine Park Authority. I would like to acknowledge all those I worked for and dived offshore with. The experience allowed me to see firsthand man's interaction with a scientific phenomenon, and the benefits of nature conservation. Finally, I would like to thank my family and friends for their understanding, support and encouragement during this extraordinary journey.

ABSTRACT

This study has developed a new life-of-field, goal orientated process of analysis called Holistic Environmental Assessment (HEA). HEA assesses the total environmental risk associated with a proposed oil and gas field development. It prioritises environmental risks and identifies cost effective strategies to reduce them. For the first time the process was applied to a real 'case study' field development programme to test its effectiveness. The application identified that it is a useful tool to help design eco-efficient and cost-effective oil and gas field developments. Furthermore, it was discovered that much of the information required by HEA could be obtained in a quick and user-friendly format.

The new assessment process was developed after a review of the interaction of the offshore oil and gas industry with the environment, and techniques employed to evaluate this interaction. The review identified that the industry interacts with the environment in a number of different ways, and that the level of interaction transgresses the boundaries of sea, air and land locally, regionally and internationally. Legislation and public concern demand no damage to the environment from offshore oil and gas field exploration and development. UK environmental legislation and people's expectations for environmental performance are in a state of change. This change, coupled with the uncertainty over how resilient the environment is to perturbation, and the increasing risk of environmental liability presents a need for operators to clearly manage environmental information and assess total environmental risk. It was discovered that Environmental Assessment, Life-cycle Analysis and Cost Benefit Analysis, when used separately, failed to assess total environmental risk, but when used in combination under the HEA process could.

Many organisations, such as the British Medical Association, European Oilfield Speciality Chemicals Association, the Royal Ministry of Petroleum and Energy (Norway) and Shell Expro, now recognise that a holistic approach is essential to assess total environmental risk. The author proposes that HEA would be effective as a software tool to analyse different environmental risk mitigation systems. This would facilitate the identification of a system that steers an operator towards the triple bottom line of Sustainable Development.

1 Introduction

1.1 UK OFFSHORE OIL AND GAS INDUSTRY

The infrastructure of offshore oil and gas installations, which has been installed in the Northwestern European Continental Shelf (NWECS), represents an investment of £150 billion in the period 1965-1996. Such a cumulative investment has enabled the UK to produce oil and gas, and allow the power generation industry to become more energy efficient, reduce damaging emissions to air and achieve independence from coal (Meenan, 1998).

Hydrocarbons from petroleum and natural gas (including colliery methane, landfill gas and sewage gas) fulfil approximately 70% of the UK demand for energy (Department of Trade and Industry, 1998a). In the early 1970s, prior to the North Sea oil and gas becoming available, energy imports accounted for over 50% of UK energy consumption. In 1983 the UK became a net exporter of energy. After 1986 net exports declined. Following temporary production losses in the North Sea, the UK became a small net importer of energy between 1989 and 1992. Since then North Sea oil and gas production has recovered, and the UK has become a net exporter again. Net exports represented 15% of inland energy consumption in 1996 and 15.5% in 1997.

Since 1975, 23 billion boe has been produced from UK offshore oil and gas fields. At the end of 1997 the remaining proven, probable and possible oil reserves stood at 2,015 million tonnes. Remaining gas reserves calculated on the same basis were 1,985 billion cubic metres at the end of 1997. The Department of Trade and Industry has estimated that in an absolute worst case scenario, the UK has extracted 67% of the total recoverable reserves of oil at present, whereas in a best case scenario 30% of total recoverable reserves has been extracted. Extracted reserves of gas are estimated at 48% and 24% of total recoverable reserves respectively (Department of Trade and Industry, 1998a).

1.2 THE NEED TO ASSESS TOTAL ENVIRONMENTAL RISK

There is always some level of environmental impact associated with the activities of man. Natural science is full of examples that highlight that the activities of any living organism cannot be undertaken without some impact on the environment. Environmental impact is demonstrated by change. This change may be at a genetic level through natural selection or at a macro-level by decreased predation or the invasion of new species in an area. Change is an essential natural and dynamic process that enables the creation and evolution of ecosystems. It is prevented where ecosystems have become fragmented and research has shown that isolating a fragment of an ecosystem thereby preventing change can lead to the extinction of some species (Newman 1993). Whether change is adverse or beneficial is an artificial concept that has developed from monitoring the implementation of conservation theory. It is the balance of change and the total level of environmental risk it presents to man, which must be measured and managed to ensure that environmental quality is maintained for future generations and their development.

Chapter 2 assesses the scope of the offshore oil and gas industry's interaction with the environment. It identifies the industry's activities that interact with the marine, atmospheric and terrestrial environments, at local, regional and global levels. It also reviews the environmental performance of the industry and highlights that there have been improvements. These are associated solely with discharges to the marine environment. This was because there were not sufficient data from operators to identify either any trends in atmospheric emissions, or trends about waste returned to shore and no data were discovered on the amount of waste discharged into the sea. Improvements will have to be documented in these areas for two reasons:

1 the current Government has proposed a staged programme to achieve its Kyoto Protocol commitment of 20% CO_2 savings of 1990 emission levels by 2010, and to accomplish it the UK Environment Minister, Michael Meacher has been encouraging companies to measure, report and reduce their greenhouse gas emissions; and,

2 after identifying that a third of the UK's top 350 companies produce no environmental information on any type of waste streams, he is also encouraging

higher standards of environmental reporting (Energy and Environmental Management, 1998).

Improvements on reducing impact on the marine environment were the result of an increase in the use of water-based muds, the shipping to shore of oil contaminated cuttings, enhanced facility drainage systems and improved oil spill contingency planning. One of the challenges the industry faces in this area will be controlling the amount of oil discharged with produced water. The total amount of oil entering the marine environment from production activities is increasing even though the concentration at which it enters is decreasing.

Chapter 4 identifies the increased awareness by environmental and fishery organisations in Norway of the far reaching consequences of particular environmental risks. This has led them to demand that future environmental risk assessments of upstream developments analyse more than just the local risks to the environment, ('local' is considered in this context as pertaining to within a kilometre of a development). They called for an assessment of total environmental risk that includes far reaching and even transboundary and global environmental risks. The Royal Ministry of Petroleum and Energy aims to achieve this using Regional Environmental Impact Assessment.

Research in Chapter 3 and 4 has highlights that a changing environmental agenda in the UK – based on concern by society that the environment is being damaged - is challenging operators to drive down their environmental impact and minimise environmental risk. This thesis identifies a toughening of environmental regulation was one of these changes. Thus, environmental risk is a key consideration in offshore field development planning. There is a need for a tool in field development planning that can assess total environmental risk, present solutions to reduce that risk, and identify the impact that such solutions will have on a proposed project's economic performance.

Chapter 4 highlights that there will always be some level of environmental risk associated with development under the assumption that any activity undertaken by man or initiated by nature poses risk to the environment through the concept of a consequential change in the state of the environment. It may be trivial and acceptable, catastrophic and unacceptable, or somewhere in between. Any group proposing that reserves could be economically exploited using a particular development programme must determine the level of environmental risk that their development will pose. The Offshore Petroleum Production & Pipelines (Assessment of Environmental Effects) Regulations 1999 for all new offshore oil and gas developments on the UK continental shelf require this. There have been other developments in the UK offshore environmental law. When considered together these laws require a wider assessment and control of environmental risk. They include: the Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000 (draft); the Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations, 1998; the Harmonised Offshore Chemical Notification Scheme; the Petroleum Act 1998 that implements OSPAR Decision 98/3; and, the Merchant Shipping (Prevention of Oil Pollution) Regulations 1997.

The challenge facing operators is not *whether* a development is designed to minimise its impact on the environment or not, but *how much* minimisation can be economically engineered into the design. Assessing how much environmental impact a development will have is of particular concern as this thesis has identified that: legislation is continually becoming tougher; compliance with legislation does not mean that there is no longer any risk to the environment; and Europeans are becoming increasingly risk adverse.

1.3 HOLISTIC ENVIRONMENTAL ASSESSMENT

This thesis presents the results of research undertaken by the author to develop a new process for the environmental assessment of offshore oil and gas activities termed *Holistic Environmental Assessment.* The objective of this process is to give an accurate account of the total environmental risk arising from offshore oil and gas development. The process assesses how offshore field developments can be designed economically to minimise risks to the environment. Figure 1.1 presents a simple overview of offshore oil and gas operations.

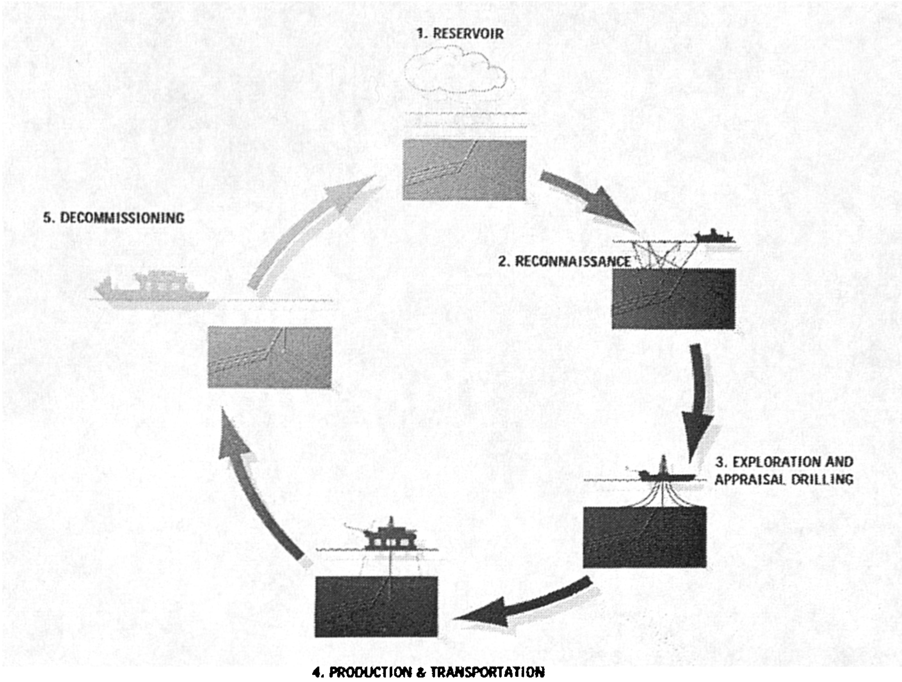


Figure 1.1 Offshore Oil and Gas Operations

Holism is from the Greek *holos* meaning 'whole', and conveys the notion that all things are connected. Research undertaken by James Lovelock to develop the Gaia hypothesis and Allan Savory to develop a Holistic Resource Management Model both highlighted the importance of understanding the interconnectedness of ecosystems. This theoretical work is supported by current experience of an environment around us that is changing both radically and dangerously, because certain conditions are posing significant risk to human life in the short and long term.

There is a key limitation with using current environmental assessment techniques in isolation to assess and manage environmental risk. This limitation is the failure to assess total environmental risk. If the key concepts behind life cycle analysis, environmental risk and impact assessment, and cost benefit analysis are combined then this limitation can be overcome. This is achieved in Holistic Environmental Assessment. The process is able to analyse information from a variety of disciplines: environmental science; economics; law; and engineering and assess total environmental risk. It prioritises environmental aspects produced by a field development and uses this information to design an environmental risk mitigation system for it that is both cost-effective and eco-efficient. The HEA process is presented in Chapter 5.

The application of HEA in Chapter 6 and the discussion of its results in 7 demonstrates how environmental externalities, obtained from a wide variety of economic studies, can be successfully used with Monte Carlo Analysis to facilitate the design an eco-efficient field development. The HEA process was designed to quantify the uncertainties, as far as possible, associated with the economic valuation of environmental resources. It was recognised however that there is further research required in this area. One of the major research recommendations by the author was that an assessment of the energy efficiency of a project and the total environmental damage of a project under the HEA process could produce an interesting environmental performance indicator to be tested. One that details the amount of damage caused per unit of energy expended.

It is the consideration of the author that if engineers in the oil and gas industry are required to meet the expectations of society as well as their organisation, and comply with legislation, it will be necessary for them: to have a clear appreciation of the impact of their operations on the environment; the legislation associated with environmental impact; the technology which is available to mitigate that impact; the economic implications of minimising the impact; and in turn be able to implement strategies which will ensure that the environmental impact of their operations is minimised (to comply at least with current legislation) in a cost effective manner. Holistic Environmental Assessment will facilitate the implementation of those strategies. Decisions made on the basis of an HEA will have the potential to reduce the impact that oil and gas operations have on the environment at local, regional and global levels.

1.3.1 Aims

The research aims to:

- identify the issues and linkages associated with the environment, technology and economics in oil and gas field development and advise on how they can be addressed in the most cost-effective manner;
- and therefore identify how industry can continue to develop and operate offshore oil and gas fields at the high environmental standards required by legislation and public expectations.

1.3.2 Objectives

The principal objective of this PhD is to facilitate the development of cost-effective strategies that will minimise the environmental impact of oil and gas field development in the northeast Atlantic. This will require an analysis and representation of the following issues:

- the potential sources of environmental aspects of oil and gas developments;
- the environmental impacts that may occur as a result of the environmental aspects;
- the current and future legislation (possible and probable) associated with environmental aspects;
- the driving stimuli behind that environmental legislation;
- the technology and techniques available to mitigate environmental impact;
- the market cost of trying to achieve a 'clean production' approach to operations;
- the non-market cost of trying to achieve a 'clean production' approach to operations.

These issues are of course currently being investigated in many organisations and by many experts. The main focus and added value that this novel research will bring will be to identify and represent, in a focused holistic manner, the relationship between these issues, and use this information to facilitate the design of offshore oil and gas field developments.

1.4 THESIS STRUCTURE

This thesis demonstrates why and how to assess holistically the environmental impacts of oil and gas extraction and production using a new process termed *Holistic Environmental Assessment (HEA).*

- *Chapter 2* identifies what the interactions are between oil and gas field development activities and the environment. It highlights trends and changes in the environmental aspects of the industry by reviewing the current environmental performance of members of the United Kingdom Offshore Operators Association.
- *Chapter 3* reviews the current environmental issues facing the industry and identifies the principal future environmental performance challenges for the offshore oil and gas industry.
- *Chapter 4* takes the environmental issues presented in Chapter 3 and, with other issues, states a case for a new process of environmental analysis. It points out the reasons why there is a need for a novel approach by reviewing the failings of current environmental appraisal techniques.
- *Chapter 5* details the framework of the Holistic Environmental Assessment process and how to conduct such an analysis.
- *Chapter 6* presents the results from applying, for the first time, an Holistic Environmental Assessment to a 'real' case study Field Development Programme, Field X, to demonstrate how the process would work in practice.
- *Chapter 7* discusses the results from the application and focuses on HEA's strengths and weaknesses.
- *Chapter 8* presents the conclusions and recommendations from the research.

Two Appendices are attached to the study:

- Appendix 1 – Environmental Aspect Models
- Appendix 2 – "Look-up" Tables for Environmental Damage Costs

2 Interaction of the Upstream Oilfield Development Cycle with the Environment

2.1 *INTRODUCTION*

The growth of the offshore oil and gas and its steady advance into the deeper waters of the Atlantic Margin in the Northeast Atlantic has raised concerns over the impact of its activities on the marine environment, fisheries and other uses of the sea. Seven years ago a study carried out by the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) evaluated the environmental impact of the wastes produced from oil exploration and production (GESAMP, 1993). They highlighted that environmental assessments should take into account factors such as relative quantities of discharges, differences between single-well exploration drilling and multi-well development and production activities, the spatial extent of effects, potential for recovery, and special environmental sensitivities. Their study concluded that the major interactions with the environment included:

- drilling muds and cuttings
- production water
- storage displacement water and ballast water.

And that minor interactions included:

- heated water
- deck drainage
- domestic sewage
- well treatment fluids
- produced sand
- desalination waste
- pipeline treatment fluids.

At the time the GESAMP report was published, the UKOOA Environmental Emissions Monitoring System was not implemented and therefore the group noted that atmospheric emissions from operations and hydrocarbon fallout from flaring remained largely unquantified. Since the GESAMP report, the Environmental Statements produced by operators have focused on these interactions. These statements have also included quantifying CO_2 emissions.

The winning of oil from the sea is a similar process to that from land, although it requires procedures and equipment that are able to cope with the hostilities of the offshore environment. The activities of the upstream oil and gas industry can be divided into the following phases, all of which revolve around understanding and managing the reservoir system:

- reconnaisance;
- exploration appraisal drilling;
- production;
- transportation by pipeline or shuttle tanker; and
- field decommissioning.

2.1.1 Environmental Aspects and Impacts

Environmental aspects are defined in the international standard for environmental management systems (EMS) ISO 14001 as any *'element of an organisation's activities, products or services that can interact with the environment'.* Exploring for and appraising potential oil and/or gas reservoirs, and developing these reservoirs have a range of environmental aspects associated with them. For example, the flaring of gas and condensate produced during well testing results in the release of SO_2, NO_X, CO_2, CO, CH_4, VOCs and the fall out of unburned hydrocarbons. Each of these aspects may result in one or more environmental impacts (actual changes in the environment) – volatile organic compounds (VOCs) release, for example, contributes to the formation of photochemical smog, global warming, and depletion of the ozone layer. This is detailed in Figure 2.1.

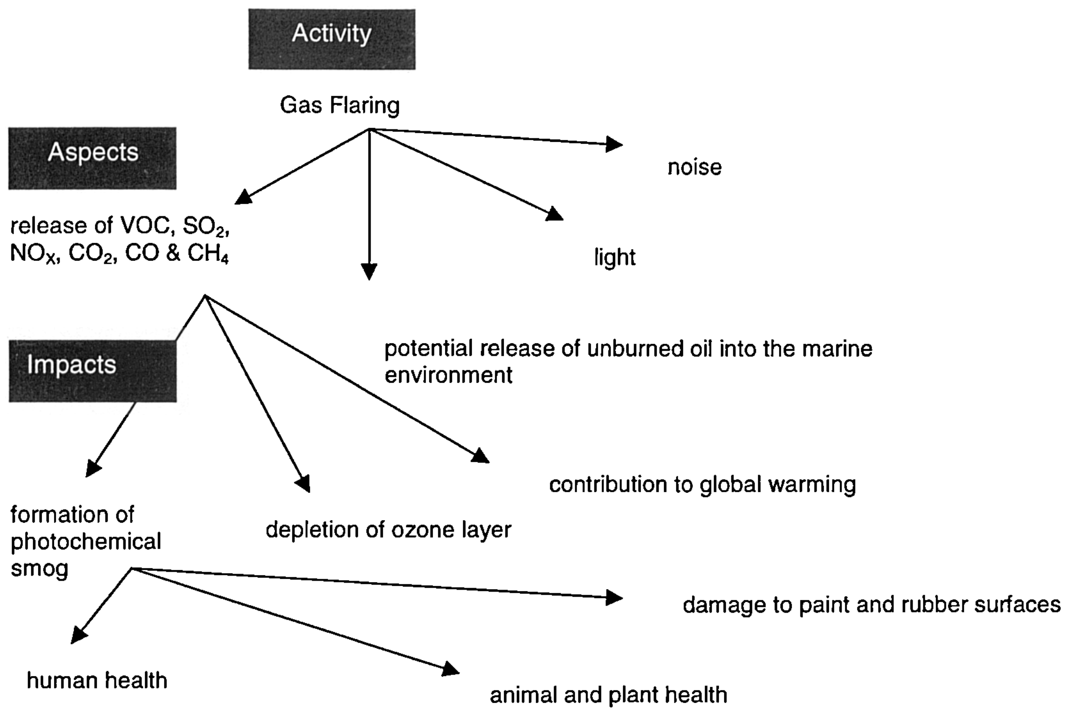


Figure 2.1. Activity Environmental Aspect and Impact Relationship

The variations in field developments produce a range of environmental aspects that can cause environmental impact. Environmental aspects may either be routine, i.e. during operations, or accidental, i.e. resulting from abnormal events. Under ISO 14001, an environmental impact is defined as *'any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activities, products or services'*. The potential environmental aspects of oil and gas field developments are detailed in the Table 2.1.

Activity	***Environmental Aspects***
Licensing	N/A
Seismic surveying	Acoustic disturbance, fuel use
Exploration	
Rig fabrication	Dredging and filling of coastal habitats
Rig emplacement	Anchoring
Drilling	Discharges and emissions, acoustic disturbance, oil and chemical additives, weighting material, solvents and lubricants
Routine rig operations	Deck drainage and sanitary wastes, domestic wastes (black and grey water)
Rig servicing	Discharges from support vessels and coastal port development
Well testing and incineration	Discharge of oil, dioxins, polycyclic aromatic hydrocarbons(PAH) and heavy metals. Exploratory drilling units are not always equipped with adequate processing facilities to stabilise the oil, collect and store it
Development and production	
Platform fabrication	Land use conflicts and increased channelisation in heavily developed areas
Platform installation	Coastal navigation channels, placement and subsequent presence of platform
Drilling	Discharges and emissions, acoustic disturbance, risk of blow-out occurring
Completion	Increased risk of oil spillage
Platform servicing	Dredging for coastal port development, discharges from supply vessels
Separation of oil and gas from water	Chronic discharges
Fabrication of storage facilities and pipelines	Coastal use conflicts
Offshore pipelines and storage facilities	Emplacement and presence, vessel presence
Pipeline operations	Inspections and maintenance (pigging and hydrotesting), risk of fracturing and chronic leakage.
Decommissioning	
Mobilisation and working of vessels at site	Presence, exhaust emissions and other discharges
Decommissioning of pipeline	Acoustic disturbance, chemical discharges by flushing pipeline and seabed disturbance
Plugging and abandonment of wells and severing of piles on platform	Metal emissions from cutting and seabed disturbance
Transportation of recovered material to shore	Exhaust emissions and discharges from vessels
Dismantling and recycling structures	Dismantling, cutting, cleaning of biofouled structures, acoustic disturbance, exhaust emissions and accidental discharges; operation of recycling plant and waste management
Post decommissioning and seabed clearance	Possible overtrawling

Table 2.1. Major Potential Environmental Aspects of Offshore Oil and Gas Developments
Adapted from Neff, 1989

The above table generalises the environmental aspects associated with offshore oil and gas activities. There can be a considerable number for a specific activity, which in turn increases the number of potential impacts.

2.1.2 Identifying Significant Impacts

Identifying impacts that are significant is an essential element of environmental assessment. Under ISO 14001 a significant environmental aspect is one that produces a significant environmental impact. There is no standardised method applied to evaluate significance. Detailed below are three of the types of methods implemented. All involve some form of screening process, which is favourable due to the volume of quantitative and qualitative data that needs to be analysed in environmental assessments. This includes identifying environmental aspects that have been scientifically demonstrated to impact on the environment. An environmental aspect is also considered significant where scientific data are inconclusive and experts consider that it may generate significant risk. Perceived risks are also being included in offshore oil and gas environmental statements as a measure of significance. Following the controversy over the Brent SPAR, wider societal-perceived risks, even when scientific evidence does not indicate significant measurable impact, are classified as significant environmental aspects. BP details this in the screening criteria principles, presented in Figure 2.2, used for their Schiehallion environmental statement.

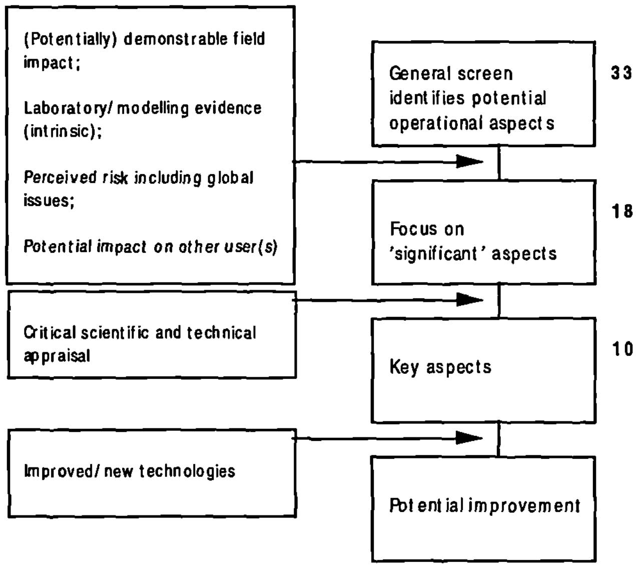


Figure 2.2. Environmental Aspects Screening Process - (Routine Operations)
Adapted from Schiehallion Development and the Environment, BP (1997a)

Draft environmental regulations for operators developing Australia's oil and gas resources specify a broad array of criteria to allow an operator to predict confidently significant environmental aspects and impacts. These criteria are detailed in Table 2.2.

1. Character of Receiving Environment	*2. Potential Impacts of Proposal*	*3. Resilience of Natural and Human Environments to Cope with Change*	*4. Confidence of Prediction of Impacts*	*5. Presence of Planning Policy Framework and 6. Other Statutory Decision-making Processes*	*7. Degree of Public Interest*
Consider Is it, or is it likely to be, part of the conservation estate of subject to treaty? Is it an existing or potentially environmentally significant area? Is it vulnerable to major induced or natural hazards? Is it a special purpose area? Is it an area where human communities are vulnerable? Does it involve a renewable or non-renewable resource? Is it a degraded area, subject to significant risk levels, or a potentially contaminated site? NOTE: Offsite as well as on site characteristics should be considered, where relevant	Consider Will construction, operation, and /or decommissioning of the proposal have the potential to cause significant changes to the receiving environment? (on site and off site, short and long term). Could implementation of the proposal give rise to health impacts or unsafe conditions? Will the project significantly divert resources to the detriment of other natural and human communities? NOTE: This should include consideration of the magnitude of impacts, their spatial extent, the duration and intensity of change, the total product life cycle and whether and how the impacts are manageable	Consider Can the receiving environment absorb the level of impact predicted without suffering irreversible change? Can land uses at and around the site be sustained? Can sustainable uses of the site be achieved beyond the project life? Are contingency or emergency plans proposed or in place to deal with accidental events? NOTE: Cumulative as well as individual impacts should be considered in the context of sustainability	Consider What level of knowledge do we have on the resilience of a given significant ecosystem? Is the project design and technology sufficiently detailed and understood to enable the impacts to be established? Is the level and nature of change on the human natural environment sufficiently understood to allow the impact of the project to be predicted and managed? Is it practicable to monitor predicted effects? Are present community values on land use and resource use likely to change?	Consider Is the proposal consistent with existing zoning of the long-term policy framework for the area? Do other statutory approval processes exist to adequately assess and manage project impacts? What legislation, standard codes or guidelines are available to properly monitor and control operations on site and the type and quantity of impacts?	Consider Is the proposal controversial or could it lead to controversy or concern in the community? Will the amenity, values or lifestyle of the community be adversely affected? Will the proposal result in inequities between sectors of the community?

Table 2.2. Criteria for the Determination of the Need for and Level of Environmental Impact Assessment in Australia

Source: Draft Petroleum (Submerged Lands) (Management of Environment) Regulations, July 1998

The Institute of Environmental Management & Assessment (IEMA) recommends that typically an environmental aspect may be significant if it:

- is controlled by legislation
- has a financial implication
- has (or the potential to cause) a demonstrable environmental effect
- is of concern to customers
- is of concern to financiers or insurers
- is of concern to the local commmunity.

Considering the above list, an assessor would need to develop a set of questions to act as a filter, to be applied to each of the aspects to determine 'significance':

- is, (or will) the issue (be) subject to legislative control?
- is the aspect/impact covered by any codes of best practice or guidelines or company policies?
- would the emergency services be involved if there were an incident?
- does the aspect have a demonstrable impact on the environment?
- is the impact likely to be the cause of complaints?
- does the impact have financial implications?
- could the impact result in financial/legal liabilities?
- is the impact likely to be of concern to shareholders and consumers?

By applying risk assessment to a set of identified significant aspects, the level of significance for each can be calculated using a subjective rating system. Certifiers of ISO 14001 agree that the area that causes the greatest amount of confusion is the identification of significant aspects and impacts (Institute of Environmental Management, 1996).

The following sections summarise the known environmental aspects associated with the various phases of activities of the offshore oil and gas industry.

2.2 LICENSING

The Department of Trade and Industry's (DTI) Oil and Gas Directorate regulates the offshore oil and gas industry using a licensing system with conditions, restrictions and Petroleum Operations Notices. Licences are granted at the discretion of the Secretary of State (SoS) for Trade and Industry. Offshore operators apply for Seaward Exploration or Production Licences. The DTI reviews applications for both types of licence and approve them on the basis of how environmental considerations are covered in their field development programme. Although no environmental impact has yet occurred, it is this phase of development that provides the opportunity to allow operators to design field developments that minimise environmental risk. The licensing procedure is detailed in Section 3.4.1.3.

2.3 *RECONNAISANCE*

2.3.1 *Operations*

The first industrial activity that takes place on the continental shelf is the geophysical survey. This evaluates an area's oil and gas resource potential based on evidence of sources, reservoirs and traps in the geological strata. It involves the pulsing of high intensity acoustic signals, using airguns, through the ocean and sedimentary strata. Although the early use of chemical explosives resulted in some destruction of marine life, current technology is thought to be safer for marine fauna and flora.

Modern large scale seismic surveys are conducted using towed arrays of air guns - cylinders of compressed air. Each cylinder contains a small volume (typically between 10 and 100 cubic inches) at a pressure of about 2000 pounds per square inch. The array, usually containing some tens of such cylinders, is discharged simultaneously, to generate a pressure pulse, which travels down to the seabed. The array of airguns is towed at a depth between 4-8 m behind a small ship. As a minimum they are submerged to a depth of one quarter of the longest wavelength of interest to ensure propagation of the waveform (Turnpenny & Nedwell, 1994). To study deep structures, large arrays with 12-70 airguns are used. The guns are fired every several seconds. A long cable containing many hydrophones is towed behind the airgun array to receive the reflected signals from beneath the seafloor. High-energy sound is received by subsurface geological structures that reflect and refract this sound. The intensity and level of which this is acquired and interpreted forms an understanding of the subsurface strata. Analysis of geophysical data gives an indication of potentially recoverable oil and gas resources, and applications for leases for exploratory drilling are made to UK Government to confirm the presence of identified potential hydrocarbon sources. Figure 2.3. details the operations required to obtain these data.

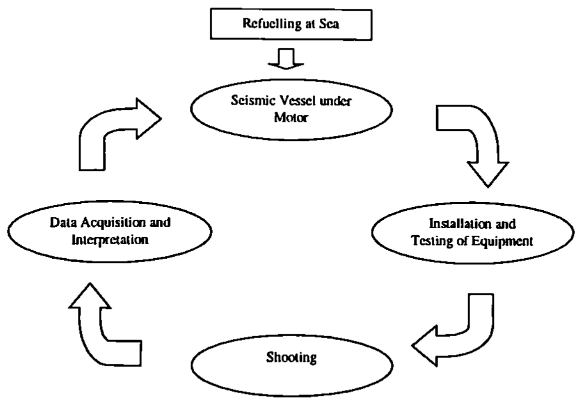


Figure 2.3. Seismic Surveying

Seismic surveys cover vast areas and are undertaken by vessels that are permanently at sea. In 1993, BP Exploration and Shell UK Exploration and Production carried out a seismic survey surrounding the Foinaven field (190 kilometres West of Shetland, blocks 204/19 and 204/24a). It covered 2050 km^2, equivalent to the London area enclosed by M25, and depths between 1300 and 2000 ft. The seismic survey market is growing such that contractors are ordering new-builds, or converting or upgrading existing vessels. The world 4D market is estimated to grow to US $1.5 bn in 1999 and the 3D market is expected to be slightly more than US $1.8 bn. In total, together with 2D seismic and multi-component acquisition, the market is expected to be more than US $3.5 bn (Thomas, 1998).

2.3.2 Environmental implications

The range of environmental aspects associated with seismic surveying include: vessel disturbance; bilge discharges; sewage discharges; acoustic pressure waves; presence of transducer array and shore beacon stations; noise and exhaust emissions from helicopter transport; litter; and, cable kerosene spillage (Davies & Wilson, 1995). The principal operations that interact with the environment are detailed in Figure 2.4.

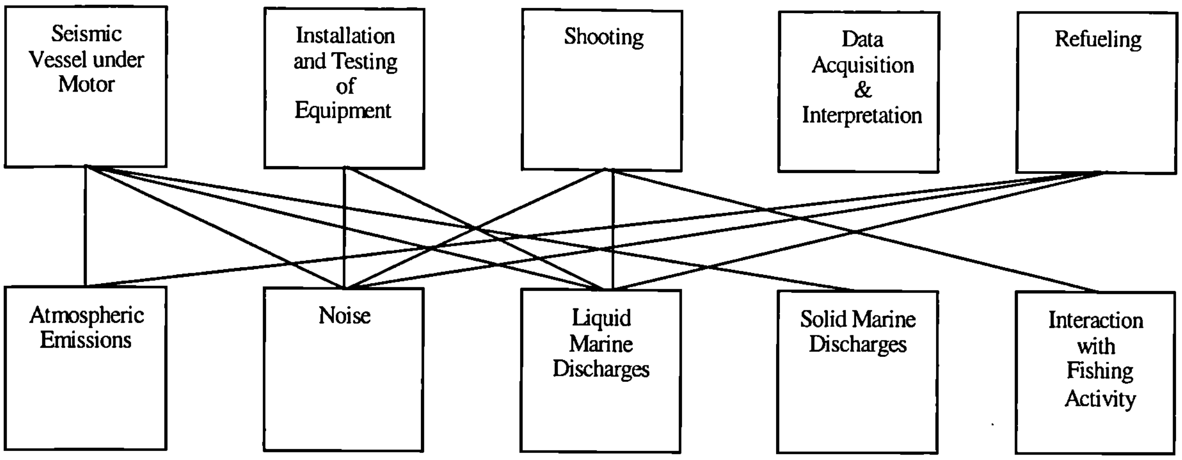


Figure 2.4. Seismic Surveying and the Environment

The aspect of greatest concern to environmental pressure groups is the use of acoustic pressure waves and their impact on fish and marine mammals. Each stage of seismic surveying and their environmental aspects is presented in further detail in the Table 2.3. and in Chapter 6.

Activity	*Environmental Aspect*
ROUTINE	
Transportation of vessel to site and along transects	Discharges to sea of oily bilge and ballast water, exhaust emissions to air from motoring
Mobilisation of air gun array and streamers	Atmospheric emissions from the power generator
Firing airgun array - venting of high pressure air into the water	Propagation of high energy, low and high frequency sounds every several seconds, atmospheric emissions from power generation
Towing of equipment several feet below surface	Presence of equipment, temporary exclusion zone. Generation of low frequency noise
Utilities and logistics	Helicopter generated noise, disposal of helifuel samples, exhaust emissions to air disposal of sewage, canteen and medical wastes onshore
ACCIDENTAL	
Streamer rupture	Release of buoyancy control (kerosene) fluid to the sea
Mishandling of materials	Oil, chemicals and persistent waste to sea, land and air

Table 2.3. Offshore Seismic Surveying Routine and Accidental Events and their Environmental Aspects

Full scale airguns (an array) generate noise pulses with very high peak levels, about 255 dB rel 1 μPa at 1 metre with a wave peak to peak time as long as 6 milliseconds (sound pressure levels are typically expressed with reference to standard pressure - usually one micropascal in water, and 20 micropascals in air and a standard distance - usually one metre) (Wardle *et al.*, 1998). Smaller arrays often have source levels of about 235-246 dB rel 1 µPa-$m_{0\text{-}p}$ (Richardson *et al*, 1995). The short duration of each pulse limits the total energy. Both high and low frequency energy is present in the pulses at considerable magnitude ranging from below 100 Hz to 22 kHz (Goold & Fish, 1998). It is the propagation of sound horizontally that is of interest as some acoustic energy is emitted into the wider marine environment (UKOOA, 1996). To improve the quality of data received for analysis and reduce wasted energy, it is desirable to minimise dissipated energy away from the seabed. Despite this focusing effect, the strong pulses projected horizontally into the water can be detected many kilometres away (Richardson *et al.*, 1995), and in the case of deep water seismic surveying such pulses have been detected over 1000 km away from source (Richardson & Wursig, 1997). Wardle *et al.* recorded a drop in sound level with distance from a full array of 231 dB at 16 m, 218 dB at 50 m, and drop to 201 dB relative to 1 µPa at 500 m. Goold and Fish detected power levels from a 2-D seismic survey at 750 m, 1 km, 2.2 km and 8 km. At 750 m range from source, seismic power at the 200 Hz end of the spectrum was 140 dB re 1 $\mu Pa^2/Hz$, and at the 20 kHz end of the spectrum seismic power was 90 dB re 1 $\mu Pa^2/Hz$. Even with background levels far in excess of ambient noise, seismic power dominated the 200 Hz – 2kHz at ranges up to 2 km from source. At 8 km, seismic power was in excess of background noise levels up to 8 kHz (Goold & Fish, 1998). The relationship between airgun source sound level and distance is detailed in Figure 2.5. Levels can vary dramatically with horizontal aspect; the strongest levels are abeam the long axis of the array and the weakest are in line with that axis (Richardson *et al.*, 1995).

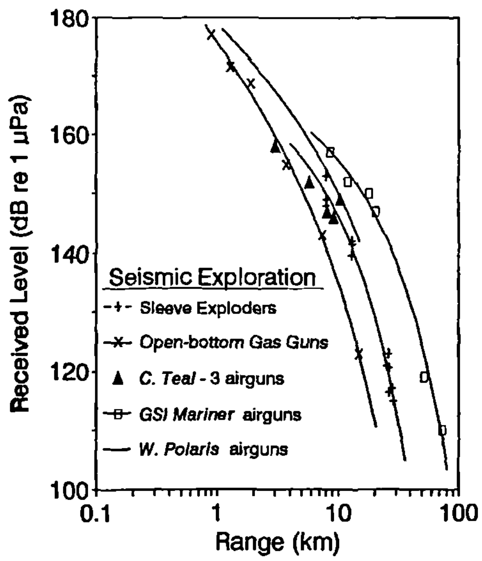


Figure 2.5. Sound Level and Distance from Airgun Source
Source: Richardson *et al.*, 1995

Signals from airguns originate as short, sharp pulses and with horizontal propagation and multiple reflections between the sea surface and bed the pulses become elongated. The primary pulse is 6 milliseconds long when emitted but can be ≥1/4-1/2 s in duration after travelling a few kilometres in shallow water. The elongated pulse tends to develop a particular pattern of frequencies as it propagates. In shallow water, it often forms a downward sweep in frequency, from ~200-400 Hz near the leading edge of the pulse to ~100-200 Hz at the end (downward chirp). In deeper waters, the pulse forms a frequency upsweep caused by the combination of multiply refracted, surface reflected sound waves (Richardson *et al.*, 1995).

Unwanted sources of noise are known as ambient noise. It is environmental background noise and includes sound generated by: wind and waves; precipitation; volcanic and tectonic activity; marine fauna; sea ice; molecular agitation (thermal noise); and sea traffic. Ambient sea noise in coastal waters, caused mainly by shipping, is around 130 dB re 1µPa at 1 m, equivalent to one million times less the air gun array. Figure 2.6 highlights ambient noise spectra.

Man-made sounds are either transient such as pulses from airguns, sonars or explosions, or continuous if they persist for long times, such as sounds from an oil drilling platform. The range of man-made noise occurring at sea is detailed in Table 2.4.

Transportation Aircraft (fixed wing and helicopters) Vessels (Ships and boats) Icebreakers Hovercraft and vehicles on ice	**Geophysical Surveys** Airguns Sleeve Exploders and Gas Guns Vibroseis Other Techniques
Dredging & Construction Dredging Tunnel Boring Other Construction Operations	**Sonars** **Explosions** Military Exercise
Oil & Gas Activity Drilling from Bottom Founded Platforms Drilling from Islands and Caissons Drilling from Vessels Offshore Oil & Gas Production Decommissioning	**Ocean Science Studies** Seismology Acoustic Propagation Acoustic Tomography Acoustic Thermometry

Table 2.4. Man-made Sources of Sound at Sea

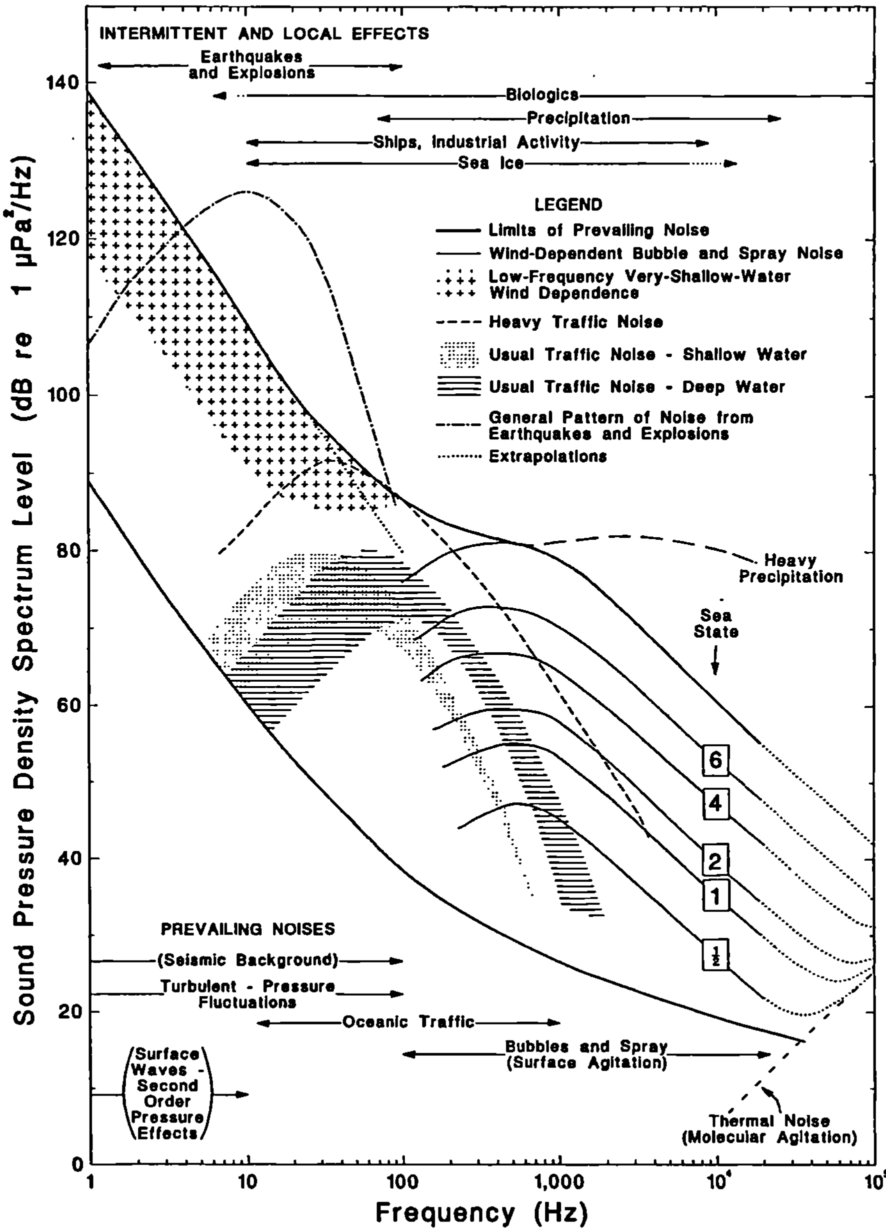


Figure 2.6. Ambient Noise Spectra
Source: Richardson *et al.*, 1995

Vessels ranging from the smallest boats and seismic vessels to the largest supertankers all produce underwater sound. Figure 2.6. illustrates that vessels are major contributors to overall background noise due to their large numbers, mobility and wide distribution. The noise produced, like aircraft noise, is a combination of narrow-band 'tonal' sounds at specific frequencies and 'broadband' sounds with energy spread continuously over a range of frequencies. The levels and frequencies of sound are dependent upon not only vessel size but also design and speed. Large vessels (over 100m) produce high sound levels at mainly low frequencies. The primary sources of sound are propeller cavitation and propeller singing (Richardson *et al.*, 1995). Table 2.5. details the sounds from large commercial ships underway.

Vessel Name	*Ship length (m)*	*Frequency (Hz)*	*(dB re 1μPa at 1m)*	*Source spectrum level (dB re 1μPa²/Hz at 1 m)*
MS Thor I (freighter)	135	41.0	172	nq
SS F.S. Bryant (tanker)	135	428.0	169	nq
SS Houston (tanker)	179	60.0	180	nq
SS Hawaiian E. (container ship)	219	33.0	181	
K Maru (bulk carrier)	-	28.0	180	173@100Hz
		36.0	180	nq
Chevron London (supertanker)	340	6.8	190	nq
Mostoles (supertanker)	266	7.6	187	153@40-50 Hz
World Dignity (supertanker)	337	7.2	185	161@100 Hz
MS Jutlandia (container ship)	274	7.7	181	nq
Third harmonic		23.0	198	nq
Fifth harmonic		38.3	186	nq

Table 2.5. Sounds from Large Commercial Ships Underway: Fundamental Frequency, Estimated Source Level of that Tone, and Measured Spectrum Level of Broadband Noise at the Specified Frequency
Source: Richardson *et al.*, 1995 (nq: not quantified)

In 1994 the Joint Nature Conservation Committee produced guidelines for UKOOA directed at minimising the acoustic disturbance from seismic surveying in areas where marine mammals may be present. These guidelines were updated in April 1998. Fisheries Research Services (FRS) have also produced guidelines for minimising such disturbance during commercial fish breeding and spawning periods (Fisheries Research Services, 1998). A precautionary combination of methods is advised by experts and includes: acoustic monitoring; visual surveys; using recommended seismic windows set by the DTI; and gradual air gun array start up (ramp-up) and shut-downs. Detecting if and where cetaceans are present within the JNCC's 500m guideline recommendation (1,640 ft) radius zone before commencing a survey is difficult particularly if the species is silent over a period of months. Such zones are designed by the radii of received levels believed to have the potential for at least temporary hearing impairment for marine mammals (Petzet, 1999). These are detailed in Table 2.6. Visual monitoring is, at best, inadequate. Observation usually begins ninety minutes before a start up and is ineffective at night, if mammals are below the surface, or when sea state is anything but calm. Continuous high level sound is considered to have a greater impact than high level transient pulses of sound (Richardson *et al.*, 1995). Industrial activities that present this hazard include dredging, drilling and shipping.

	*Mysticetes**	*Odontocetes*	*Pinnipeds*
Alaska (Beaufort Sea) Northstar 1997	1020 mα 3,346 ft	1020 mα 3,346 ft	260 mβ 853 ft
Southern California (Santa Barbara Channel) Santa Ynex Unit, 1995	450 mα 1476 ft	152 mβ 500 ft	152 mβ 500 ft
Washington/British Columbia (Puget Sound region), SHIPS, 1998	500 mχ 1640 ft	200 mδ 656 ft	100 mε 328 ft
UK 1994 to present	500 mϕ 1640 ft	500 mϕ 1640 ft	500 mϕ 1640 ft

*This category includes sperm whales for some surveys. αThe distance at which the received level was estimated to be 180 dB re 1 μPa at 1 m for the largest array used. βThe distance at which the received level was estimated to be 190 dB re 1 μPa for the largest array used. χAn additional 100 m was added to the distance at which the received level was estimated to be 180 dB re 1 μPa. δThis was twice the distance at which the received level was estimated to be 210 dB re 1 μPa. εThe distance at which the received level was estimated to be 210 dB re 1 μPa. ϕA distance at which cetaceans may be reliably observed.

Table 2.6. Safety Zone Radii Employed During Recent Seismic Surveys
Source: Petzet, 1999

2.4 DRILLING

2.4.1 The Process

Drilling involves exploration, appraisal and development drilling. Consequently the process may be employed at any time during the search for, development of and life-extension of a field. The Department of Trade and Industry carefully monitors drilling activity and statistics are published monthly in UK Energy Trends. Table 2.7. details UK drilling activity that includes sidetracked wells. From the Table it is clear that drilling to develop and extend the life of fields accounts for the greatest effort.

Year	Number of Wells Started Offshore			
	Exploration	Appraisal	Exploration and Appraisal	Development*
1994	62	37	99	202
1995	60	38	98	244
1996	77	35	112	261
1997	63	35	98	256
1998	47	33	80	281
% Change	*-25.4*	*-5.7*	*-18.4*	*+9.8*
1997 3rd ¼	14	8	22	59
1997 4th ¼	16	4	20	61
1998 1st ¼	14	9	23	78
1998 2nd ¼	11	5	16	61
1998 3rd ¼	14	8	22	71
1998 4th ¼	8	11	19	71
1999 1st ¼	7	3	10	75
1999 2nd ¼	4	4	8	57
1999 3rd ¼	3	9	12	55
% Change	*-78.6*	*+12.5*	*-45.5*	*-22.5*
* Development wells are production wells drilled after development approval has been granted				

Table 2.7. Drilling Activity on the UK Continental Shelf
Source: Department of Trade and Industry, 1999a

Drilling equipment will vary depending on the type of rig used, the available technology and the environment. However, in principle, the method remains the same. Initial drilling into the seabed is known as 'spudding in'. The well is drilled using a drill bit connected to the rig via a drill string that transmits the torque driven by a rotary system or 'top drive system'. The drill bit, under the weight of the drill string, grinds the bedrock producing cuttings. These cuttings need to be removed to maintain drilling efficiency so a drilling fluid (drilling mud) is circulated across the bit by pump pressure. Figure 2.7. presents the drilling process.

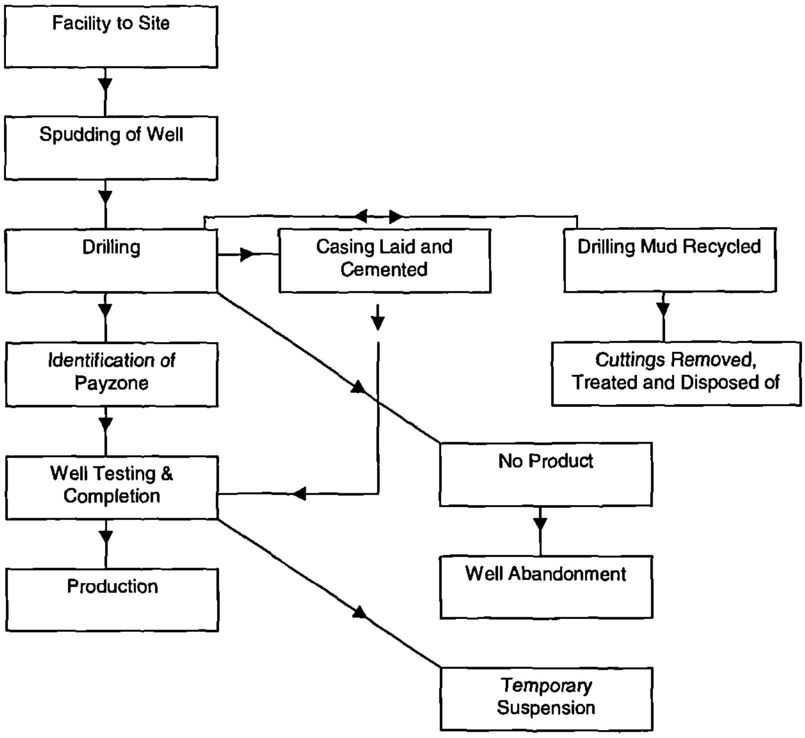


Figure 2.7. The Drilling Process

The drilling fluid also has other important functions such as to cool and lubricate equipment (especially the bit face) and to maintain wellbore stability whilst drilling. The latter is achieved by designing a fluid of the appropriate density (i.e. 'weighted' with a heavy solid such as barite) which will prevent borehole collapse or a kick being taken (a sudden surge of formation fluids and/or gas into the well). Inadequate control of kick could result in a blow-out of oil and/or gas occurring from the well. The consequences of which could cause considerable economic and environmental damage, or worse, the loss of human life. It is for this reason that wells and drilling processes are constantly monitored during drilling.

2.4.1.1 Pressure Control

Wellbore stability is also maintained by the construction of a pressure control system that includes the periodic laying of borehole casing strings. Its primary function is to isolate and control potentially troublesome formations. The casing is attached to the borehole wall using cement. If a kick is taken then the increase in borehole pressure can be controlled by blow out prevention equipment until it is 'circulated out' using a choke system.

Exploratory wells are plugged and abandoned where no oil or gas is found. In the UK the industry follows UKOOA's guidelines on abandoning wells in accordance to specifications contained in the drilling lease from the Department of Trade and Industry (DTI). If an oil and gas reservoir is found and the well is to produce then the well is completed. This is achieved by one of three bottom hole preparation techniques:

- open hole completion
- screen or pre-slotted liner completion
- casing or liner with annular cementation and subsequent perforation.

The method chosen depends on the geology and geophysics of the reservoir. The third is the most widely applied bottom hole technique as it offers the greatest potential to control the production area referred to as the 'pay zone'. How the oil is to flow out of the well and fluids injected into the well (to increase productivity) is determined by the selection of a flow conduit between the reservoir and the surface. There are a number of methods available. Production tubing with annulus isolation is the most widely used method for well completion of a single pay zone. It offers maximum well security and control.

2.4.1.2 Completion & Testing

Completion fluids and workover fluids are viscosified brines to eliminate 'plugging solids' in the wellbore. The majority of brines are $CaCl_2$ based though $ZnBr_2$ may be used where high densities are required. To minimise the costs and risks associated with drilling a well, the operator must analyse prospects before committing resources. A temporary test of a well after it is drilled is undertaken for this purpose. This is in addition to the seismic surveys and geological analysis of well cores. It is the information obtained from a well test that determines the economic viability of the field and is therefore an important factor in determining the field's design configuration. There are two types of well tests available: drillstem tests and extended well tests. Drillstem tests are commonly used and provide near-wellbore reservoir information. Since actual hydrocarbon production during a drillstem test is normally limited to several hours or days, the hydrocarbons are normally burned. Extended well tests provide enough data for a more complete description of the reservoir. Hydrocarbon production could last for several weeks or months, depending on the size of the reservoir; therefore the oil is normally stored in a tanker and the gas is either flared and/or used to produce power for the production facility.

2.4.1.3 Facilities

The wells drilled are exploration wells, termed in the industry 'wildcat wells'. The exploratory drilling phase requires mobility as only 2-4% of exploratory wells drilled world-wide result in the finding of oil at the bottom (Sharples, 1992). There are three types of mobile structure used:

- a jackup rig;
- a drill ship or;
- a semi-submersible.

Economic and environmental conditions determine which facility is used. In shallow waters, jack up rigs can be towed out and its retractable legs can be lowered to the seabed for stability and position. The maximum depth that these rigs can safely operate is 350 ft. They cannot be used where the seabed is too soft to give adequate support, or where strong currents may cause scouring. In very shallow waters the legs make the rig 'top-heavy' increasing the risk of toppling, and conventional land-based rigs are constructed on jetties running from the coast. These operate in depths up to 100 ft. In some areas these platforms can be considerable distances offshore. In the Caspian Sea stockades or causeways were constructed by the former Soviet Union to create offshore roads between individual drilling platforms situated about 50 km offshore from Baku (Davies G, 1997). In shallow waters, beyond the reach of jetties, artificial islands may be created. The increased cost of purpose built structures led to the introduction of mobile floating structures.

Drillships were introduced in the 1950s for exploratory drilling in deeper waters using converted naval vessels. Originally the vessel was positioned using anchors, which restricted its operating depth to 2000 ft; current technology enables a drillship to operate to depths of 10,000 ft using dynamic positioning thrusters. Drillships are equipped with both anchor mooring and dynamic positioning. The vessels are restricted to fairly sheltered areas (offshore West Africa and the Mediterranean) and can be used in iceberg environments (Labrador Coast). Drillship technology has also been developed to enable scientists to explore deep into ocean bedrock to study the history of the Earth and the oceans. In 1968, the US Glomar Challenger was constructed to drill in oceans 6 km deep and collect core samples from thousands of feet within the ocean bedrock (Segar, 1998).

Semi-submersible rigs (submerged pontoons) were developed to enable drilling in deeper waters (up to 1500 ft) and were designed to minimise the effect of heavy seas on operations. The rig is not bottom supported and can be designed to float (such rigs are commonly called 'floaters'). Since the position of the rig is constantly changing specially equipment needs to be installed before drilling can proceed.

The same method of drilling is used whether in exploration or production. Directional and deviated drilling technology (i.e. away from the vertical) has enabled multiple well drilling to occur from a single platform or vessel allowing the development of smaller scattered fields that were previously technologically uneconomic. Further technological innovations in drilling such as Extended Reach Drilling, Coiled Tubing Technology and Under Balanced Drilling are furthering the limits of offshore oil and gas exploration and production.

2.4.2 Environmental Implications

Drilling operations include: primary drilling (drilling prior to the field being on line for production), completion and testing; well workovers, stimulation and sidetracking; information gathering and well maintenance. Their interactions with the environment are detailed in the Figure 2.8.

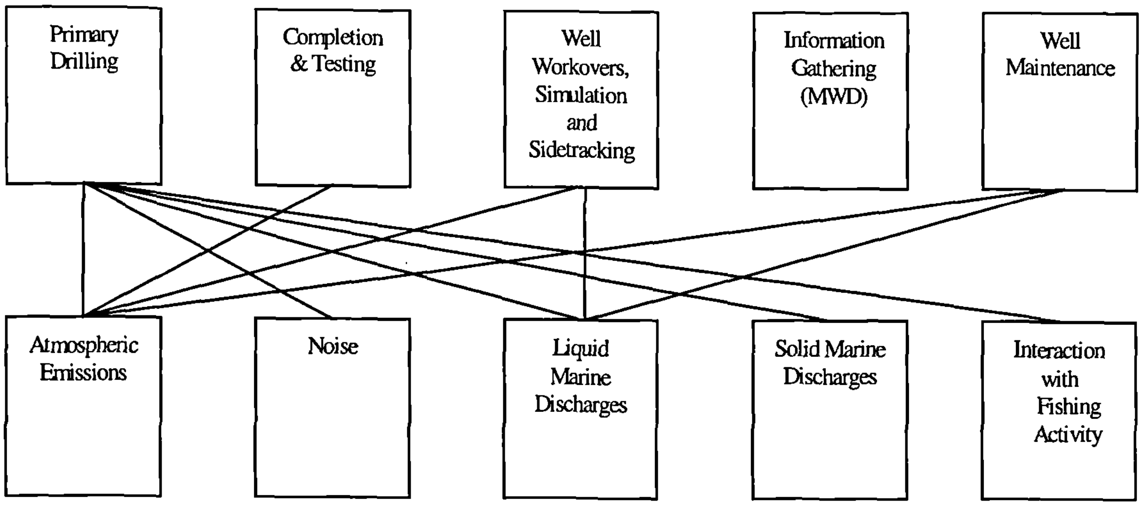


Figure 2.8. Drilling and the Environment

The North Sea Quality Status Report 1993 concluded that the major source of oil from oil and gas activities arose from the disposal of cuttings on the seabed. The report estimated that 2% of the total North Sea had been affected by oiled drilled cuttings at its time of writing. Since the 1 January 1997 all oil based cuttings have been disposed of onshore (DTI, 1998b).

There is a range of environmental aspects associated with exploration and appraisal drilling. These are presented in Table 2.8.

Activity	*Environmental Aspect*
ROUTINE	
Rig fabrication	Dredging and filling of coastal habitats
Rig/drill ship transport including the motoring of other vessels (cargo barge, crane vessel, associated tugs and other support vessels	Interaction with other users of the sea, formation of a 500 m exclusion zone, presence of a new marine substrate and artificial offshore island
Hook-up and commissioning	Atmospheric emissions from generator used to power crane
Anchoring and ballasting the facility	Physical disturbance to the sea bed from anchoring, increase in localised turbidity, resuspension of sediments, discharge of ballast water
Drilling top hole	Marine discharges and atmospheric emissions, oil and chemical additives, weighting material, solvents and lubricants. This section may be drilled with seawater reducing discharges to sea. Generation of low frequency noise
Drilling bottom hole	Marine discharges and atmospheric emissions, oil and chemical additives, weighting material, solvents and lubricants. Generation of low frequency noise
Cementing casing	Marine discharge of cementing chemicals
Well testing and incineration	Marine discharge of oil, dioxins, polycyclic aromatic hydrocarbons(PAH) and heavy metals. Exploratory drilling units are not always equipped with adequate processing facilities to stabilise, collect and store the oil
Drilling Module Ventilation (integrated extract fans with built in fans and coolers)	Fugitive vapour losses to air from oil base and water base muds of 0.25-0.5m³/hr. Losses vary on the mud and cement system design
Bulk Material Handling (barite, cement, bentonite, whole mud, base oils or other base fluids)	Losses to sea due to on-platform transfer and loading, or accidental hose failure
Chemical Handling	On-platform handling, disposal of residual drilling chemicals in containers onshore.
Wireline and well treatment (workovers)	Venting of well pressure will result in the emission of gas to air and/or discharge of oil to sea
Well Clean-up & Testing (Completion)	Flaring of oil, gas and/or condensate, unburned hydrocarbons fall to sea
Power generation	Atmospheric emissions from combustion units
Spent and unused drilling fluids and chemicals	Spent and unused OBM & SBMs conditioned and reused. Returned to supplier. WBMs discharged offshore.
Rig deck drainage using pressurised water hoses and bilges	Drainage of drilling areas can have a very high volume - oily discharges to sea, chemical discharges to sea
Vessel ballasting	Ballast water discharged to sea
Disposal of sewage, canteen and medical wastes	Solid waste discharged to sea. Hazardous and special waste disposed of onshore
Vessel/helicopter transportation	Exhaust emissions to air. Disposal of Helifuel samples onshore
Rig servicing	Marine discharges from cleaning rig. Atmospheric emissions from painting topsides. Discharges and emissions from support vessels and coastal port development
Suspending well	Presence of structure on the seabed, presence of anodes and coatings
Abandoning well	Removal of structure, metal emissions to the seabed
ACCIDENTAL	
Mobilisation of facility and support vessels, crane vessel and cargo barge	Overboard spillage of chemicals or solids, dropped objects
Collision	Overboard spillage of chemicals or solids, dropped objects
Structural failure - Collapse of drilling derrick	Chemical discharge and persistent waste to sea
Drilling	Venting of gas from gas surge or kick, toxic gases encountered, mishandling chemicals with spillage to sea, blowout releasing mud, cuttings, oil, gas, condensate and mud additives to sea and air. Loss of drilling mud to sea due to a blockade of 'mud cleaners'
Facility utilities and logistics	Helifuel spillages during refueling operations; release of halon in case of fire

Table 2.8. Offshore Drilling and Environmental Aspects

2.4.2.1 *Cuttings and adhering fluid & waste drilling fluids*

Drilling fluid composition varies considerably within the industry. There are three main types - oil based muds, water based muds and synthetic based muds. Under special circumstances a drilling fluid may not be used. For example seawater may be used for the initial spudding stage, or under exceptional circumstances, compressed air may be used when drilling hard formations such as granite. The type of drill mud used is chosen on the basis of potential technical and economic problems. The constituents of a mud are chosen to control density, lubricity, fluid flow, corrosion and scale. Oil based muds are primarily used in drilling high angle, extended reach wells or in high temperatures or hydratable shales. They are used to overcome technical difficulties such as hole instability, stuck-pipe, differential sticking, and loss circulation. Technical difficulties may damage equipment, increase drilling time and therefore capital and operational expenditure for the project will rise. 'Mud cleaners' at surface remove cuttings from the drilling fluid before the mud is recirculated. The cuttings are either dumped *'in situ'* or transported onshore dependent on operating regulations, the mud used, and preferred company practice.

The use of OBMs has been on decline on the UKCS since 1989 and, consequently the amount of oil discharged with contaminated cuttings has also declined. Currently no cuttings from wells drilled using OBMs are discharged to sea. This is detailed in Table 2.9. Following the introduction of PARCOM Decision 92/2 requiring discharges to sea of 10 g of oil/kg cuttings dry weight, since January 1997 UKCS oil based mud cuttings have been transported onshore for disposal. The skip to shore process is adopted as it is currently technically impossible to achieve the discharge threshold. OBMs may be rented, or sold and repurchased by the supplier. This recycling technique ensures that only contaminated cuttings are disposed of (Veil *et al.,* 1996). The use of OBMs is limited not only by the discharge threshold but also by (1) the added cost of hauling and disposing of wastes onshore and (2) the long-term liability associated with onshore disposal sites. OBM disposal methods onshore are considered a pressing environmental issue (Petroleum Engineer International, 1992).

	1987[1]	1988	1989[1]	1990[1]	1991	1992	1993[1]	1994	1995	1996
Wells drilled using OBM	176	252	266[2]	260[3]	249[4]	196[5]	150[6]	102[7]	94[8]	79
Oil discharged (tonnes)	12400	18500	13400	12310	11230	7169	4588	3820	3180	3826
Wells drilled	258	345	337	348	33	372	288	309	342	374

Note: Side-track wells are included as separate wells from 1989 onwards
[1] Figures vary from those in other Brown Books
[2] Includes 6 wells spudded in 1988 but which did not use OBM until 1989
[3] Includes 20 wells spudded in 1989 but which did not use OBM until 1990
[4] Includes 22 wells spudded in 1990 but which did not use OBM until 1991
[5] Includes 20 wells spudded in 1991 but which did not use OBM until 1992
[6] Includes 16 wells spudded in 1992 but which did not use OBM until 1993
[7] Includes 12 wells spudded in 1993 but which did not use OBM until 1994
[8] Includes 6 wells spudded in 1994 but which did not use OBM until 1995

Table 2.9. Oil Discharged on Drill Cuttings 1987-1996
Source: Department of Trade & Industry (1997)

In an international survey by Petroleum Engineer International (PEI), operators stated that they used water based drilling muds 82.3% of the time, and oil based muds 17.7% (PEI, 1992). In Table 2.10. the US Environmental Protection Agency identified that this pattern continued into the late 1990s.

Drilling Fluid	*Shallow Water (<1000ft)*		*Deep Water (≥1000ft)*		*TOTAL WELLS*
	Develop.	*Explor.*	*Develop.*	*Explor.*	
Gulf of Mexico					
Total Wells Drilled Annually	645	358	48	76	1127
Wells Drilled Using WBM (10%)	560	311	12	19	902
Wells Drilled Using SBM (10%)	13	7	36	57	113
Wells Drilled Using OBM (10%)	72	40	0	0	112
Offshore California					
Total Wells Drilled Annually	11	0	15	0	26
Wells Drilled Using WBM	10	0	4	0	14
Wells Drilled Using OBM	1	0	11	0	12
Coastal Cook Inlet					
Total Wells Drilled Annually	7	1	0	0	8
Wells Drilled Using WBM	6	1	0	0	7
Wells Drilled Using OBM	1	0	0	0	1

Table 2.10. Estimated Numbers of Wells Drilled Annually by Drilling Fluid in US
Source: Environmental Protection Agency, 1999

Water-based muds (WBMs) are aqueous slurries of barite clay and formation solids that usually contain low concentrations of polymer lignites, lignosulphonates and caustic soda. They may also contain low concentrations of other materials. Minor constituents of water-based drilling muds include inorganic salts, surfactants and detergents, corrosion inhibitors, lubricants (diesel and mineral oils as spotting agents or pills, and as unique lubricants in the form of an oil-in-water emulsion), biocides and a variety of speciality additives for unique drilling problems. WBMs are considered as low toxicity mud. Their use is encouraged by the DTI to minimise environmental impact. The base mud composition for a WBM, showing the components common to nearly all muds, is detailed in Table 2.11.

Component of mud	*Amount (pounds per barrel)*
Bentonite	0 to 50
Barite	0 to 500
Caustic soda	0 to 5 (can be substituted by caustic potash)
Soda ash	0 to 3 (can be substituted by sodium bicarbonate)
Sodium bicarbonate	0 to 3 (as soda ash)
Sea water	Any proportion
Fresh water	Any proportion - normally in prehydrated bentonite)
Drill solids	0 to 100

Table 2.11. Simplified Water Based Drilling Mud Composition
Source: Joint Group of Experts on the Scientific Aspects of Marine Pollution, 1993

The formulation of WBMs is changing with increasing environmental demands for lower toxicity additives. Thus they are continually evolving. The voluntary Offshore Chemical Notification Scheme controls the level of discharge of particular chemicals using a chemical group trigger limit system. Chemicals are classified into groups according to toxicity, biodegradability and their potential to bioaccumulate. Group A is the most hazardous group and -E the least. If a trigger limit for a particular group might be reached, consultation with the DTI to discuss alternative chemical usage is advised to minimise environmental impact. Figure 2.9. shows the total amount of WBM drilling chemicals per group discharged into the sea from a total of 318 wells during 1998.

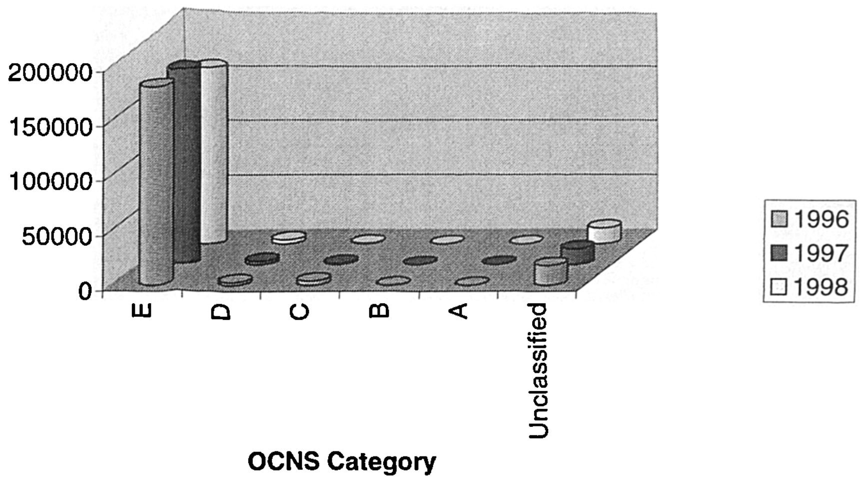


Figure 2.9 Amount of WBM Drilling Chemicals Discharged to Sea Per Category
Source: UK Offshore Operators Association, 1999

Adherence to OCNS warrants offshore disposal of WBMs and WBM contaminated cuttings. This follows a dump and dilute schedule e.g. 25% of mud system disposed of and replaced with 25% new mud. The amount of mud dumped in this manner is highly dependent on the mud system.

For any given well or sidetrack the amount of drilled rock is a function of hole size and section length. In the North Sea area, typical consumption of oil-based muds is in the order of 1-2 m^3 drilling fluid/ m^3 of rock drilled, whilst for water based systems a much wider range of 5-15 m^3 drilling fluid/ m^3 of rock is more typical. These figures relate to the total losses from the system (excluding used drilling fluids at section end) not just the losses of drilling fluid directly adhering to the cuttings. Ester systems suggest figures similar to OBM. Developments in WBM technology has produced glycol fluids that are consumed in the 3-8 m^3/ m^3 range and cationic polymer fluids in the 5-10 m^3/ m^3 range.

Synthetic based mud systems or pseudo-oil based muds were developed to harness the benefits of drilling with an oil based mud and to reduce environmental impact by improving mud biodegradation performance. SBMs are generally considered less toxic and hazardous when compared with diesel and conventional OBMs (Meinhold, 1999). In SBMs a synthetic fluid forms the continuous phase while brine serves as the dispersed phase. There are several synthetic based mud systems used by the drilling industry. These SBMs are classified according to the molecular structure of synthetic base fluids: esters, ethers, linear alpha olefins (LAOs: C_{14}-C_{20}), polyalphaolefins (PAOs; C_{20}-C_{24}) and olefin isomers. Like OBMs, SBMs are recycled and only the contaminated cuttings are discharged into the sea. Discharge controls have been applied to SBMs:

- all synthetic based muds are subject to a 10% 'oil-on-cuttings' discharge limit
- the monitoring of oil discharged with cuttings is to be accomplished by a mass balance method
- a reduction in oil discharge is required at a rate of 20% per year, from the 1996 figure
- the 20% per year reduction is to last to 2001 when the discharge of oily cuttings would only be allowed at the level of 1%.

As the 2001 deadline approaches, the controls in place have become increasingly stringent. Figure 2.10. highlights that the objective of zero discharge by end-2000 may be achieved and companies are making greater reductions than targeted. There is a move away from 'oil-on-cuttings' as a basis of control. Emphasis is now placed on limiting the absolute quantity of oily cuttings discharge irrespective of its oil content (Thomas, 1999).

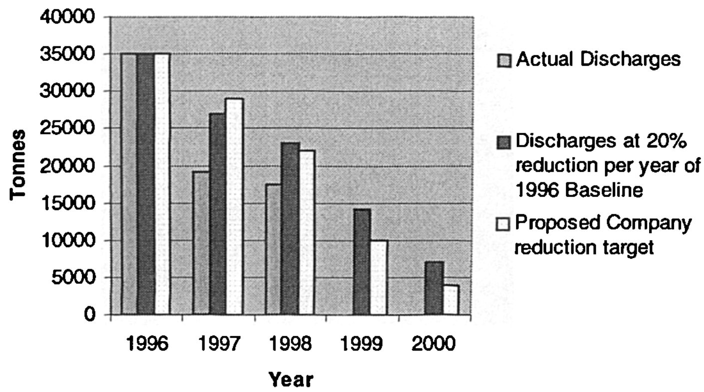


Figure 2.10. Synthetic Drilling Fluids Discharges
Source: Department of Trade & Industry, 1999

Spent and unused SBMs will no longer be discharged offshore if the 1% remains impracticable, but, like OBMs, will be taken ashore for treatment, re-conditioning or disposal, or injected into a subsurface facility offshore. Onshore treatment and conditioning of OBMs and SBMs for re-use involves removing fine accumulated drilled and weighting solids by centrifugation. This waste material is disposed of to landfill, landfarming, incineration and biological treatment sites. Incineration and biological treatment residues are generally disposed of to landfill sites. Disposal routes of OBM and SBM cuttings produced by UKOOA member companies in 1998 are detailed in Table 2.12.

Base Fluid	*Number of Wells*	*Quantity of Cuttings (tonnes)*	*Disposal Route*	*Quantity of oil/fluid on cuttings (tonnes)*
Synthetic	30	13,428	Shore	1,356*
Synthetic	120	54,367	Discharged to Sea	5,005
Synthetic	3	1,643	Injected into the Well	136*
Oil	12	1,837	Shore	250*
Oil	7	1,357	Injected into the Well	196*
*Not discharged to sea				

Table 2.12. Disposal Routes & Quantities of Cuttings Disposed of by UKOOA Member Companies in 1998
Source: UK Offshore Operator's Association, 1999

2.4.3 Atmospheric Emissions from power generation & well completion and testing

2.4.3.1 Power Generation

Drilling for oil and gas produces significant volumes of waste gases. These gases include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), sulphur dioxide (SO_2), methane (CH_4) and volatile hydrocarbons (VOCs). The main source of CO_2 is the combustion of fuel gas and diesel for power generation processes. Figure 2.11. illustrates the emissions to air of CO_2 during the drilling. It identifies that the major source of atmospheric emissions is fuel gas, which accounts for almost 60% (1,462,841 tonnes) of CO_2 emissions.

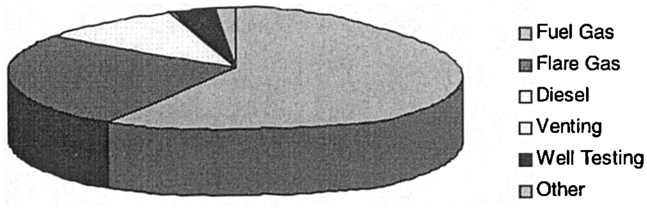


Figure 2.11. CO_2 Emissions from Drilling
UK Offshore Operators Association, 1999

2.4.3.2 Flaring

The flaring of gas is a safety precaution. Most oil fields produce associated gas and have to contend with the potential eventuality of kicks and blowouts. The flare acts as a pilot so that if necessary large volumes of gas can be diverted to the flare and safely ignited and burned off. The global warming potential ratio of CH_4 to CO_2 is 21:1 (over 100 years) which makes the burning CH_4 as a flare a more suitable option for any surplus gas problem. However the challenge is to eliminate any flaring (or venting). This may be achieved by: gas injection for improved oil recovery; liquefaction of the gas for LPG exports; storing surplus gas in depleted reservoirs; transporting it ashore by pipeline. The options are dependent upon the volumes of associated gas produced and the economics of preventing flaring.

Flaring combustion efficiency determines performance. Poor combustion will result in liquid drop out and part-pyrolised materials occurring. This is, of concern, when the burner unit is used for hydrocarbon-contaminated solids and chemicals including spent acids. Unburned hydrocarbons that fall to the sea during flaring are treated as an oil spill and cleaned up using processes detailed in an operator's oil spill contingency plan.

2.4.3.3 Well Testing

The DTI considers any well test with a total flow duration of more than 96 hours or which produces a total of more than 2000 tonnes of oil to be an extended well test (EWT), which will require application for a specific EWT Consent. A formal Environmental Impact Assessment is likely to be required if the volume of oil and gas flared during an EWT is significant (Department of Trade & Industry, 1999e). The laying of a pipeline to collect gas and prevent flaring from a minor well test is uneconomical. Well testing releases significant volumes of hydrocarbons into the air and sea. When wells are drilled in the exploration and appraisal phase, a mechanism for hydrocarbon storage or transportation does not normally exist. As a result, hydrocarbons from a well test must be burned or stored in temporary facilities. In near-shore environments the predominant environmental issues to consider are fallout of oil and/or clouds of smoke during burning. This may cause beach fouling and danger to plants and animals on the littoral fringe and large black plumes of smoke that are unsightly. Operators have to ensure that the best environmental and economic disposal method is selected and this is achieved on a well by well basis (MacFarlane, 1996). Tankers may be used to collect oil from such tests e.g. Statoil have developed the Crystal Sea (a specialised clean-up and well testing vessel that can collect oil that would otherwise need to be flared due to a lack of available infrastructure). This cuts emissions to air and hydrocarbon spillage to sea and provides financial gain to the operator (Statoil, 1998).

2.4.3.4 Oil Spillage

UK law requires that any oil spillage be reported to the nearest coastguard station and to the DTI. They are accidental events that if large in size have the potential to cause extensive damage. Large oil spills from upstream oil and gas drilling activities may occur from a blow-out, or an accident involving the loss of oil-based drilling mud or diesel fuel to the sea. Fortunately such events are rare. The risk of a rig blowout with oil spillage (based on historical international data) is within the order of magnitude of 10^{-4} - 10^{-5} (Sharples, 1992). Table 2.13. details diesel fuel and diesel mud spill frequency calculated from PON 1 returns to the UK DTI; 1982-1997 (ERT, 1998).

Diesel Spill Frequency	***Spill Size (tonnes)***	***Number of Spills***	***Number per Facility Year***
	<0.1 te	15	0.0067
	0.1-<1	17	0.0076
	1<5	7	0.0031
	5-<25	5	0.0022
	25-<50	0	0
	50	1	0.0004
Diesel Mud Spill Frequency			***Number per Wells Drilled***
	<0.1 te	9	0.0040
	0.1-<1	27	0.0121
	1<5	65	0.0290
	5-<25	62	0.0277
	25-<50	12	0.0054
	50	8	0.0036

Table 2.13. Diesel Fuel & Mud Spill Frequency
Source: Environment and Resource Technology, 1998

2.4.3.5 Other

Sound is a form of pollution associated with drilling that is rarely detailed in Environmental Statements. Sound from drilling from natural barrier islands or man-made islands is generally weak and continuous, and is inaudible at ranges beyond a few kilometres. Drilling from bottom-founded platforms is under-studied, but evidence suggests that noise levels are low. Noise levels are stronger from drillships and semi-submersibles. They are generally higher near drillships than semi-submersibles, detectable for ~10 km above local ambient levels. Semi-submersibles do not exceed these levels beyond ~1km. Drilling noise includes strong tonal components at low frequencies, including infrasonic frequencies (Richardson *et al.*, 1995).

2.5 PRODUCTION & TRANSPORTATION

2.5.1 Production Facilities

The production facilities are selected and configured on the basis of the specific needs of a reservoir. No two reservoirs are identical. There is therefore no standard equipment configuration for an offshore production systems. By generalising the design and configuration of the equipment used, the following offshore production systems can be identified:

- Fixed Platform;
- Subsea Tie-back;
- Semi-submersible with Catenary Anchor Legged Moored (CALM) buoy/ and Floating Storage and Offloading (FSO) unit;
- Semi-submersible with Pipeline Export;
- Floating Production, Storage and Offloading System
- Turret Moored Tankers; and
- Single Well Offloading System (SWOPS).

The technology used for a production system is chosen to optimise the economics of field development. In recent years economic factors have driven the development of technologies to enable fields to be developed which a decade ago would not have been feasible or practicable. The 1986 oil price crash forced the industry to develop low cost techniques that would make the development of smaller, marginal fields profitable. This has promoted a greater use of unfixed infrastructure in the UK. Since 1974 type of oil and gas production platforms installed on the UKCS is highlighted in Figure 2.12.

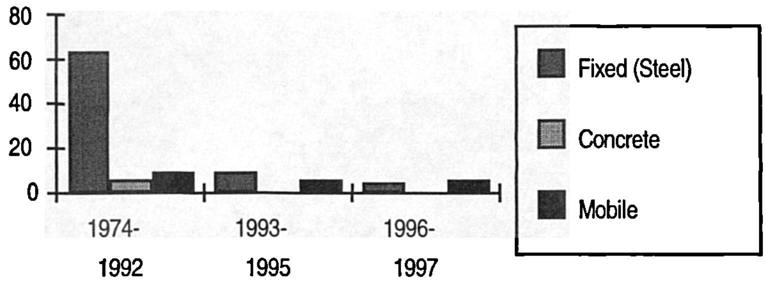


Figure 2.12. Oil and Gas Production Platforms Installed on the UKCS since 1974 - 1997
Adapted from DTI 1997

In a study to develop a knowledge-based system for economic analysis and risk assessment of small oil field developments in the UK North Sea, it was discovered that the majority (90%) of future developments will involve a subsea tie-back to an existing facility or the use a FPSO (Dyer *et al.*, 1996).

Offshore production systems can be split into two main types, oil production and gas production. Both operations produce quantities of oil, gas and water. The relative amounts depend on the type of field and its age. For technical and economic reasons it is normal to separate and treat the three streams at the offshore facility, prior to exporting oil and/or gas.

2.5.1.1 Produced Oil

Crude oil is a complex mixture of hydrocarbons with 4-26 or more carbon atoms in the molecule. Arrangements include straight chains, branched chains, or cyclic chains including aromatic compounds (with benzene rings). Some polycyclic aromatic hydrocarbons (PAH) are known to be potent carcinogens. Sulphur and vanadium compounds are also included in crude oil and non-hydocarbons may represent up to 25 percent of the oil. The exact composition of crude oil varies from one field to another. Much of the North Sea oil is light, with little sulphur and is low in tars and waxes. Oil from the Beatrice field in the Moray Firth and that to West of Shetland is a very heavy, waxy oil which needs to be heated in order to pump it through pipelines. The composition of the crude oil also varies during the life of a single oilfield.

Oil production facilities are usually larger than gas production facilities since significant quantities of gas and water are usually produced along with the crude oil, making separation and treatment facilities complex. In the North Sea, many oil production fields maintain sufficient pressure by injecting water into the reservoir. Thus as the field matures, and the pressure decreases, more water is produced with the oil known as 'high water cut'.

2.5.1.2 Produced Gas

Produced gas is principally methane. Gas production facilities produce mainly gas along with small quantities of condensate (light, liquefiable hydrocarbons) and water. Gas condensate fields produce light crude along with an abundance of dissolved gas (dissolved at downhole temperatures and pressures).

2.5.1.3 Production System

A production system rarely consists of a single producing well, more often it is a multi-well, possibly multi-reservoir, system of producing wells with flowlines, primary process facilities and delivery lines. The design of the facilities has to deal with the uncertainty represented by the lack of full knowledge of the initial state of the reservoir. This limits the ability to predict how the reservoir will behave once reservoir fluids are produced. Unforeseen characteristics will affect equipment conditions and field economics.

Maximising production rates and thus a field's Net Present Value is the primary objective of any company undertaking the commercial venture of producing oil and gas. Hydrocarbons produced for export need to meet sales or delivery specifications whether to pipeline or tanker. Production technology and techniques are complex and diverse and are involved in the following operations:

- well productivity assessment;
- well completion performance;
- well stimulation;
- associated production problems mitigation;
- remedial actions and workovers;
- surface oil and gas processing; and
- produced water and injection water treatment.

Production, by its very nature, involves the extraction of hazardous substances, crude oil and natural gas. There are two forms of possible pollution from production: (1) the generation of contaminated waste and (2) the leakage of material streams to the environment. Non-petroleum material entering the environment from production processes is either naturally occurring, such as formation waters and produced sand, or deliberately added chemicals facilitating production operations.

2.5.2 Downhole Operations

Downhole production operations include primary, secondary and tertiary recovery methods, well workovers and well stimulations. Primary Recovery refers to the initial production of oil or gas from a reservoir using only natural pressure to drive the product out. Most reservoirs are capable of producing in this way, however this ability declines over the life of the well and secondary recovery will be required. Eventually all wells towards the end of their production profile will employ some form of secondary recovery. This phase involves artificial lift methods to drive the product from the reservoir, by water flooding or gas lift using surface and subsurface pumps. The injection of gas or liquid into the reservoir maintains pressure. Water flooding, by injecting treated fresh water, seawater or produced water is the most frequently employed secondary recovery method. Tertiary recovery refers to the last portion of the oil that can be economically produced. Chemical, physical and thermal methods may be used in combination for tertiary recovery. Chemical methods include: injecting fluids containing substances such as surfactants and polymers. Miscible oil recovery involves the injection of gases, such as carbon dioxide and natural gas, which combine with the oil.

Workovers aim to restore or increase production from wells whose flows are inhibited by downhole mechanical failures or blockages, such as those caused by sand or paraffin deposits. Fluids circulated into the well for this purpose must be compatible with the formation and not adversely affect permeability. Wellbore stimulations are designed to enhance a well's productivity through fracturing or acidizing. Fluids injected during these operations may be very toxic (hydrochloric acid) and may be produced back to the surface after petroleum production is resumed. Other chemicals may be periodically or continuously pumped down a production well to inhibit corrosion, reduce friction or simply keep the well flowing. For example, methanol may be pumped down a gas well to keep it from plugging with ice.

2.5.3 Surface Operations

Surface production operations generally include gathering the produced fluids (oil, gas, gas condensate and water) from a production well, or group of wells, and separating and treating the fluids. During production operations, pressure differentials tend to cause water from adjoining formations to flow into the producing formation (water breakthrough or water coning). In time, production water/oil ratios may increase steeply. Mature wells will produce significantly more water. Over 99% of water in oil must be removed in accordance with delivery specifications. The oil may also contain chemical additives such as corrosion inhibitors, biocides and fungicides. Oil-water mixtures may be separated by gravity in a series of large or small tanks. However, fine emulsions cannot be separated in that way and require heat applied using 'heat-treaters'. Whichever method is used crude oil flows from the final separator to stocktanks. Solids and liquids that settle out of the oil at the tank bottoms e.g. produced sand is collected along with the separated water for disposal.

Natural gas requires different treatment techniques to separate out crude oil, gas condensates, entrained solids and other impurities. Separation processes may occur in the field, in a gas processing plant, or both. Crude oil, gas liquids, some free water and entrained solids can be removed in simple separation vessels. Low temperature separators (knock-out drums) remove additional condensates. There is a risk of water and hydrocarbons forming crystalline hydrates at low temperatures, i.e. below 70°F. Several dehydration processes, using ethylene glycol (a liquid desiccant counterflow process) or silica gel (a solid desiccant) removes water. These separation media may be regenerated and used again, but eventually they lose their effectiveness and require disposal.

Both crude oil and natural gas can contain acid gases, which are generally carbon dioxide and hydrogen sulphide. Hydrogen sulphide is a highly toxic gas. 200 ppm in air is lethal to humans. If an offshore field has a significant content of acid gas and a dedicated pipeline, the normal procedure is to transport the sour gas to shore after dehydration for a treatment referred to as sweetening. Sweetening involves counterflowing the product with a suitable wash agent, such as an amine (ethanolamine or diethanolamine), in a bubble cap tower to remove the acid gas. Any employed removal process results in spent and waste separation media, which must be disposed of. At onshore plants, where hydrogen sulphide is removed from natural gas, sulphur dioxide is produced and from this sulphur can be recovered as a commercial by-product. Hydrogen sulphide dissolved in crude oil does not pose any risk until it is produced at the wellhead in gaseous form, from where it poses serious occupational health and safety risks through possible leaks or blowouts.

Oil, gas and condensates produced offshore, to delivery specifications, must eventually be transported to shore for refining, processing and consumption. The means of conveyance will vary for different fields depending on the product and the amount of production, the distance to shore, the nature of the intervening environment, and the capacities of onshore facilities.

2.5.4 Transportation

There are two modes of transporting oil and gas the choice of which is determined by the products' physical chemistry, reservoir location and field economics:

1. to load tankers at sea, a process which requires an offshore storage facility; or
2. to pipe it ashore.

Transportation by shuttle tanker is likely to be chosen if an oil field is small with limited satellite field opportunities and far from any existing infrastructure. Pipelines are used for oil and gas fields to tie into existing pipeline networks of fields and where the development economics favours pipeline construction.

2.5.4.1 Shuttle Tankers

Hydrocarbons from frontier offshore fields are transported by vessel, at least until production makes pipelines economically feasible. Tankers transporting produced oil from frontier fields are termed "shuttle tankers", since they transport the oil a short distance to a shore terminal i.e. undertaking "shuttle-runs". It is rare for the field operators to own the shuttle tankers transporting oil downstream.

The operator is responsible for the loading of a shuttle tanker with oil from an offshore installation and is liable for any spillage within the 500 m exclusion zone. Outside the zone and the environmental liability is transferred to the shipping company that owns the shuttle tanker. Shipping companies are chosen carefully to ensure the suitability of their service and their tankers (including bowloading equipment) are approved by the developers to ensure that they meet safety and environmental standards.

2.5.4.2 Pipelines

In the North Sea, virtually all the oil and gas produced flows through pipelines to an extensive offshore pipeline network connected to shore by a terminal. Pipeline diameter varies from 6 inches for small intrafield lines to 36 inches for several of the main export trunklines. Wall thickness varies in accordance to the required pressure rating capabilities. There are three categories of pipeline that transport produced oil, gas and condensates, and are classified according to the link provided by them in the transport chain:

1. **Intrafield lines** carrying a product from subsea installations to either another subsea installation or a production platform
2. **Interfield lines** carrying product from one production facility to another or to a connnection on another pipeline and their function is usually limited to the transportation of oil and gas to the next link in the pipeline system to the shore terminal; and
3. **Trunklines** are the last link in the pipeline transportation system to shore and are exclusively for the transportation of the product to the shore terminal.

The majority of submarine pipelines are intrafield flowlines associated with field development and are protected from other users of the sea by a 500 m exclusion zone around an offshore production platform. The oil produced for export is transported to a shore terminal where it is either refined or processed for sale and delivery to a refinery. A refinery is 'downstream' of the oil and/or gas production unit, and a petrochemical plant is usually downstream of a refinery. Hence, all operations occurring after the delivery or lifting of saleable quality oil and gas from the production unit or associated delivery terminal are referred to as being 'downstream'.

Shore terminals need to be located as close as possible to drilling and extraction rigs to reduce transportation distances and hence field development costs. Shore terminals comprise of loading or unloading facilities in a transportation system for oil or gas e.g. pipeline-to-tanker, tanker-to-refinery, trunk pipeline-to-rail tanker, refinery-to-road tanker. They may also contain processing and storage facilities. Examples of UK oil terminals include Sullom Voe in Shetland and Flotta in Orkney. The former is large, receiving 1 million barrels of crude oil to be processed per day, stored and loaded on board tankers bound for British and foreign ports. Supply bases are located in traditional ports to be close to offshore industry activity.

2.5.5 *Environmental implications*

The production and transportation phases of a field's life-cycle may last over 20 years and thus any gradual, routine releases of pollutants occur over a longer time scale compared to any other phase. The design of an installation and choice of transportation will influence the range and significance of subsequent environmental impacts during and at the end of the life of a reservoir. For example, the choice of fixed or mobile platforms will pose different types of hazards to the environment. The Eighth Report by the Royal Commission on Environmental Pollution in the UK on Oil Pollution of the Sea identified two pollution hazards associated with using floating offshore production systems:

1. the requirement of more piping and equipment on the seabed unprotected by surface structures; and ;
2. the need to load and store oil offshore.

Production and transportation operations involve oil and/or gas processing and transporting the products onshore where further processing may occur. Processing may be simple or complex depending on the produced fluids. The interactions with the environment are detailed in the Figure 2.13.

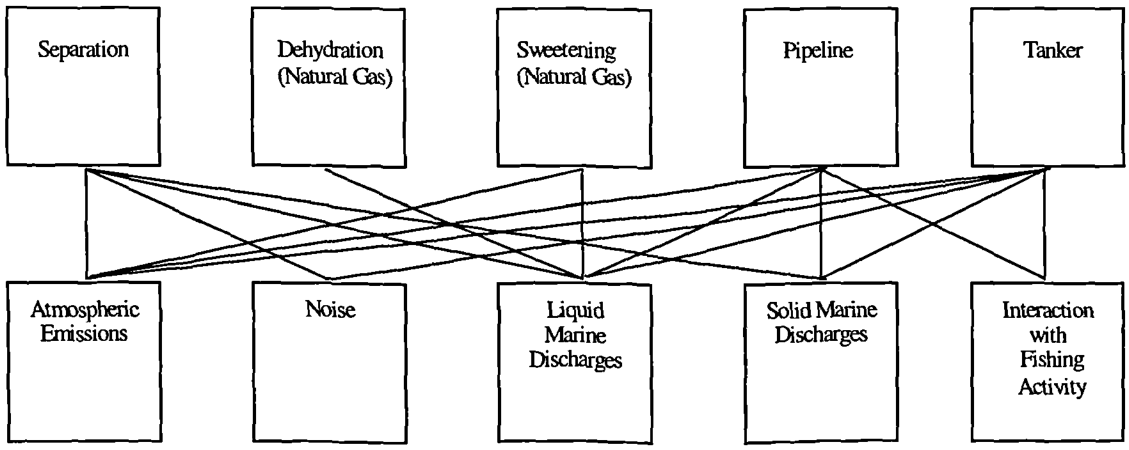


Figure 2.13. Production, Transportation and the Environment

2.5.5.1 Production

There is a wide range of environmental aspects, which occur from production operations as a result of (1) the complicated processes that are involved to allow production to continue economically and (2) the presence of people living on the platforms. The number of people working offshore can range from zero in the case of subsea tie-backs to around 1000 on a few multi-platform fields. On a large single platform there may be 300 people working offshore (Environment and Resource Technology, 1995). There are other production systems that, being situated below the surface of the sea are unmanned. The key environmental aspects associated with production are: produced water (where water is required for oil reservoir pressure control); production chemicals; oil and gas processing wastes; atmospheric emissions from power generation, flaring and fugitive emissions; and domestic waste (sewage, washing and platform cleaning water). The environmental aspects associated with production are detailed in Table 2.14.

Activity	*Environmental Aspect*
ROUTINE	
Facility	Physically covering parts of the seabed
Primary Recovery	None
Secondary recovery	Water or gas injected into reservoir to increase and maintain pressure. Atmospheric emissions from fuel to power injection
Tertiary Recovery	Chemicals injected such as surfactants and polymers. Atmospheric emissions from fuel to power injection
Workovers and stimulations	Venting of well pressure may result in the emission of gas to air and/or discharge of oil to sea. Any chemicals used (HCl, CH_3COOH) require removal and disposal
Crude Oil Processing - Primary and Secondary Separation & Acid Gas Removal - Sweetening (heat treatment for heavy crudes)	Separated gas surplus flared Removal of any unwanted solids (salts), liquids (produced water, chemical additives) or gases (H_2S, CO_2) Oily wastes Dehydration and sweetening wastes Produced sand
Light Oil Processing - Primary and Secondary Separation & Acid Gas Removal - Sweetening	Separated gas surplus flared or processed Removal of any unwanted solids (salts), liquids (produced water, chemical additives) or gases (H_2S) Oily wastes Dehydration and sweetening wastes Produced sand
Natural Gas Processing - Primary and Secondary Separation & Acid Gas Removal - Sweetening	Removal of any unwanted solids (salts), liquids (produced water, chemical additives) or gases (H_2S) Oily wastes Dehydration and sweetening wastes Produced sand
Emulsion formation	Emulsions treated with heat, settling time and chemical demulsifiers Untreatable emulsions require disposal
Scale Formation (Calcium, Barium, Strontium scales)	Removed by drilling out Barium and Strontium scales naturally radioactive (low level) requiring disposal
Injection Water Treatment	Removal of fine solid materials and organic material (bacteria, algae) using filters and biocides. Discharge of filter backwash and water softeners
Chemical Handling	Unloading and on-platform handling, disposal of chemicals in containers onshore.
Wax and Asphaltene Formation	Disposal of wax, asphaltenes and chemical inhibitors
Equipment cooling	Discharge of large volumes of cooling water treated with chlorine (nb thermal)
Gas safety purge	Flaring of oil, gas and/or condensate, unburned hydrocarbons fall to sea
Power generation	Atmospheric emissions from combustion units
Spent and unused chemicals	Used solvents, cleaners, completion fluids and spent acids require disposal; Unused chemicals either reused or returned to supplier or discharged offshore; Used lubrication and hydraulic oils
Facility deck drainage using pressurised water hoses and bilge water	Drainage of deck during workovers and stimulations can have a very high wastes volume - oily discharges to sea, chemical discharges to sea
Facility and Support Vessel ballasting	Ballast water discharged to sea
Disposal of sewage, canteen and medical wastes	Solid waste discharged to sea. Hazardous and special waste disposed of onshore
Vessel/helicopter transportation	Exhaust emissions to air. Disposal of Helifuel samples onshore
Facility servicing	Marine discharges from cleaning rig. Atmospheric emissions from painting topsides. Discharges and emissions from support vessels and coastal port development
ACCIDENTAL	
Accidents transferring materials from supply vessels to facility	Overboard spillage of chemicals or solids, dropped objects
Collision	Overboard spillage of chemicals or solids, dropped objects
Abnormal reservoir events	Venting of gas from gas surge or kick, toxic gases encountered, mishandling chemicals with spillage to sea, blowout oil, gas, condensate to sea and air.

Table 2.14. Production Environmental Aspects

Produced water is a mixture of formation water, breakthrough injection seawater, production chemicals and unseparated produced oil. It is discharged to sea. The regulatory limit governing the discharge is detailed in section 3.4.2.2. Producing oil reservoirs in the North Sea are maturing and require greater breakthrough injection seawater (see 2.5.3). This is increasing the total quantity of hydrocarbons being released into the North Sea by produced water. Efforts are being directed to reduce this aspect by minimising the amount of oil discharged with water using hydrocyclones and centrifuges. The Figures 2.14 and 2.15. illustrate these trends.

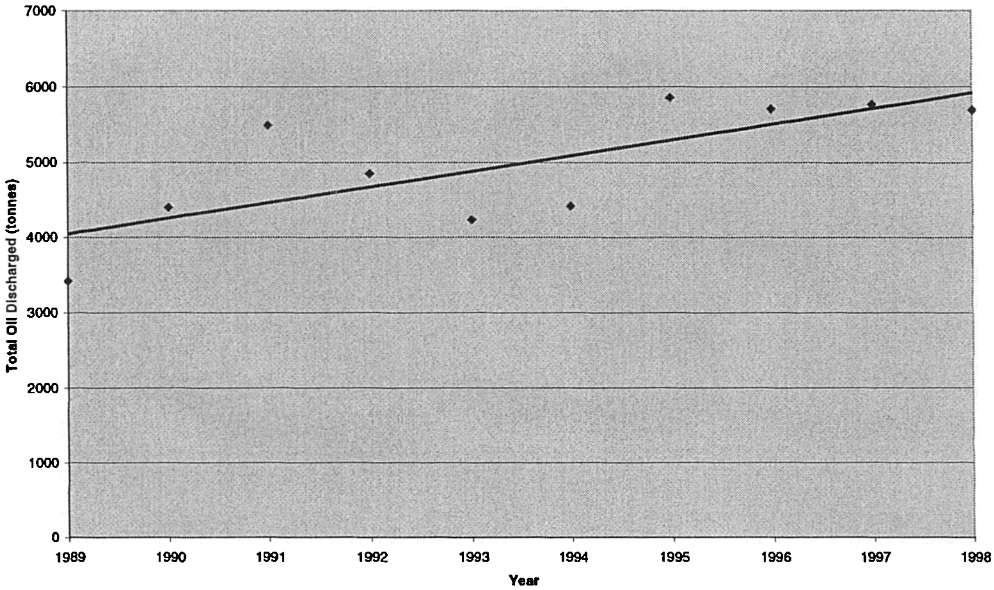


Figure 2.14. Total Oil Discharged with Produced Water by UK Upstream Oil and Gas Operators
Source: DTI, 1999f

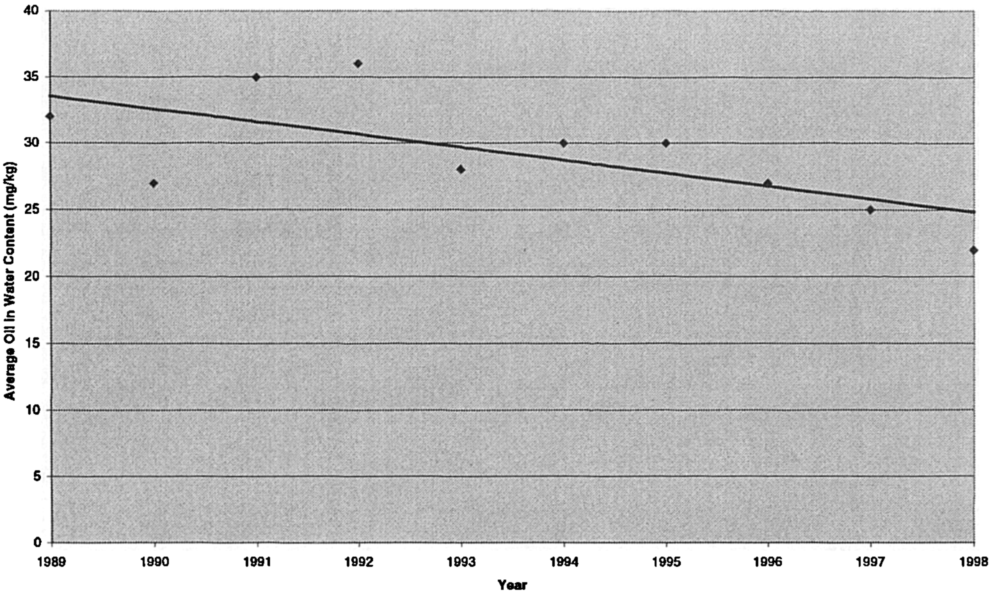


Figure 2.15. Average Amount of Oil in Produced Water
Source: DTI, 1999f

Chemicals such as corrosion inhibitors, biocides and emulsifiers are added at various points during the production process. Small amounts of the oil-soluble chemicals dissolve and are exported with the product, while a proportion of the water-soluble chemicals dissolve in the produced water. The quantity of production chemicals used varies from year to year depending on reservoir characteristics and, among other things, the quantity of oil and gas produced. This is presented in Figure 2.16.

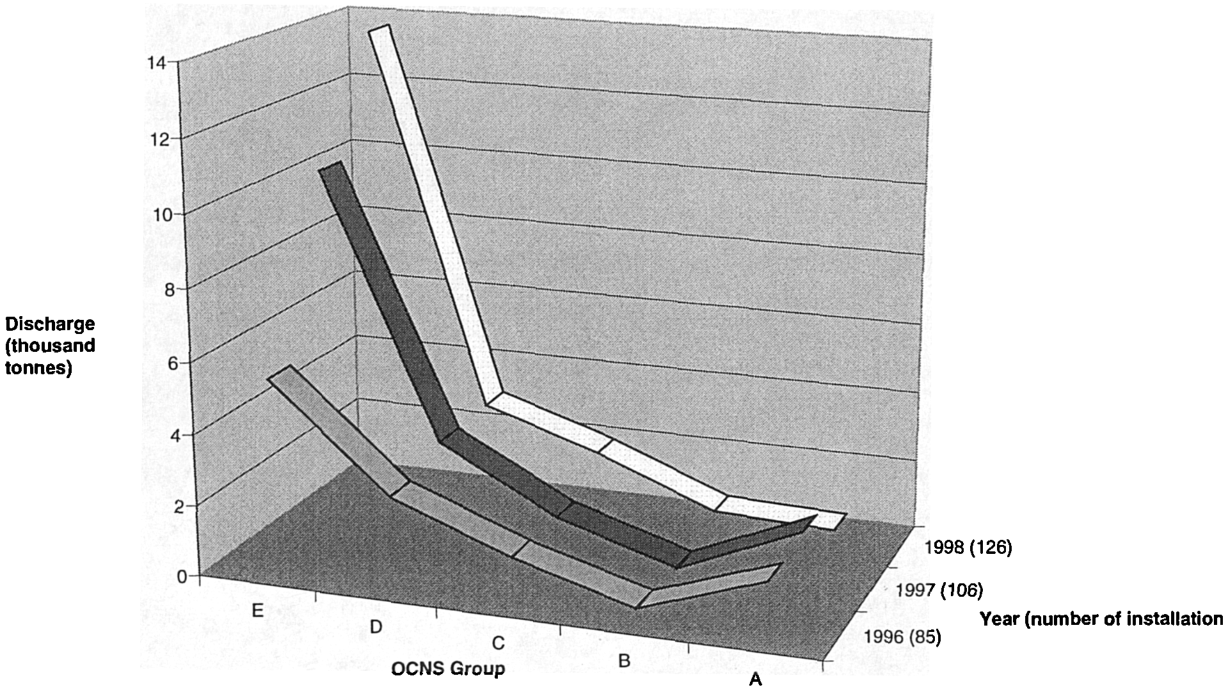


Figure 2.16. Production Chemicals Discharged to Sea
Source UKOOA, 2000

Production platforms need power but are often located in remote offshore locations and cannot be connected to the National Grid. Large amounts of electrical power may be generated at the production location and some combustion plant will have a 50-megawatt thermal input level or above. Gas- or diesel-driven turbines are used. Gas turbines are frequently operated offshore, as produced fuel gas is available and it is at a low cost. Power generation produces emissions to air of CO_2, CO, NO_2, N_2O, SO_2, PAHs and particulates. Other sources of combustion emissions from production platforms include gas flaring, well testing, and the gas turbine-powered compressors used to export gas to onshore terminals. Figure 2.17. identifies that fuel gas is the greatest source of combustion source emissions and contributes to the greatest proportion of CO_2 emissions from offshore oil and gas production. Gas flaring also contributes a significant amount of CO_2 emissions to the air. The total amount of gas flared offshore in 1998 was calculated to be 1,886,572 tonnes by UKOOA members (UKOOA, 2000).

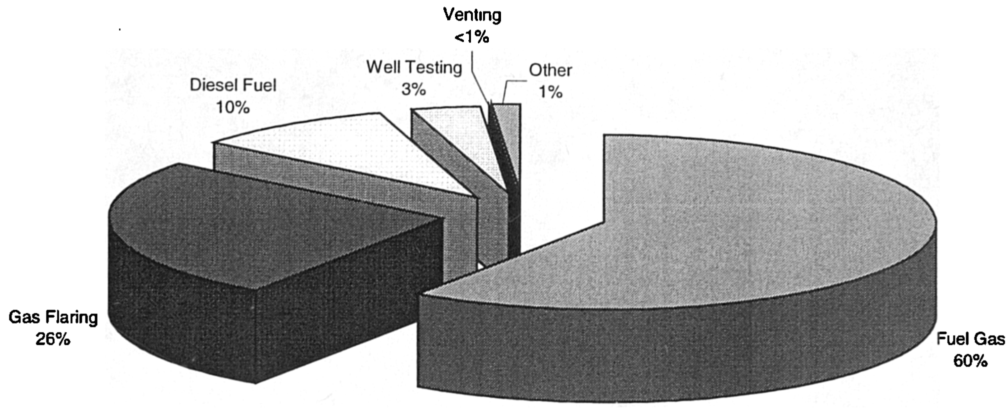


Figure 2.17. Sources of CO_2 Emissions from Offshore Oil and Gas Production
Source: UKOOA, 2000

Other emissions from production operations include:

- CH_4 (methane) – see Figure 2.18.
- VOCs (volatile organic compounds) – venting and fugitive emissions; offshore loading
- CFCs (chlorofluoro/bromo carbons)– refrigeration, foam blowing and fire fighting.

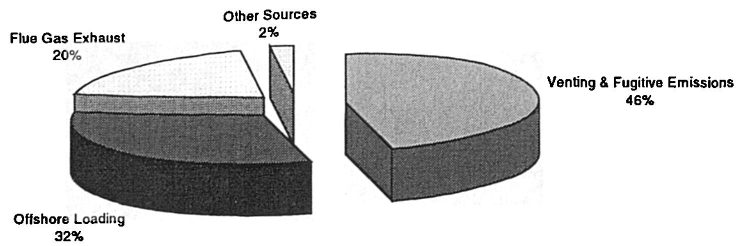


Figure 2.18. Sources of Methane Emissions from Production
Source: Hatamain, 1997

The total emissions of different gases to the air from oil and gas production platforms are illustrated in Figure 2.19. These figures have been calculated using data on the quantities of fuel gas and diesel fuel burned by each UKOOA member, as well as the quantities of gas flared or vented under consents issued by the DTI.

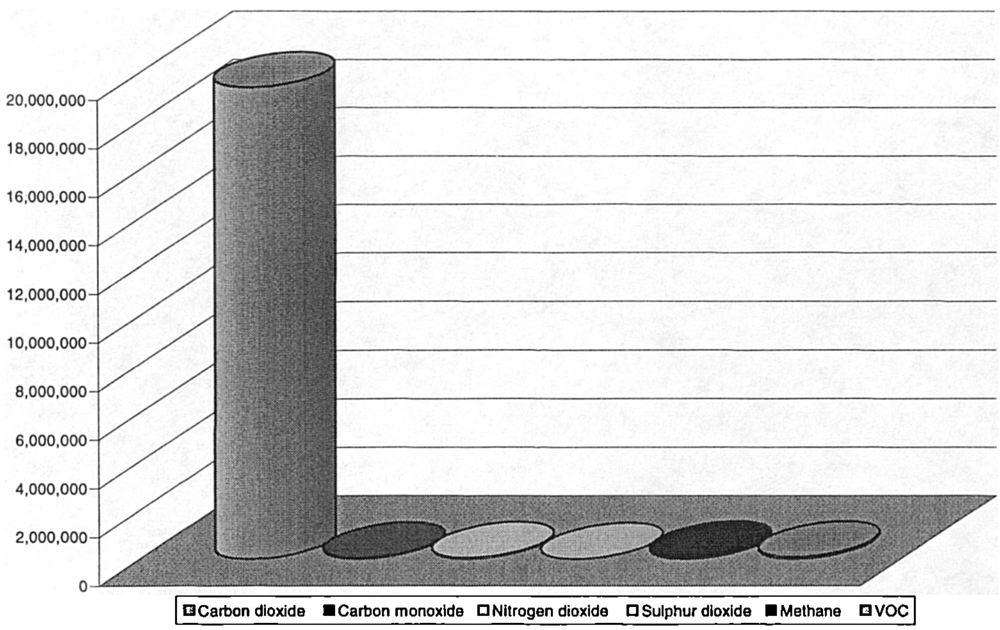


Figure 2.19. Total Emissions to Air from Oil and Gas Production Platforms between 1996 to 1998
UKOOA, 2000

Like any onshore industry, the offshore oil and gas business generates a variety of wastes for disposal (that need to be disposed of). These range from unique materials such as rock cuttings through construction, operating and maintenance wastes such as wood, metals, electrical materials, chemicals and oils. Since offshore installations are small communities, they also generate domestic waste such as housekeeping, catering and small amounts of clinical waste (UKOOA, 1999). The International Maritime Organisation has designated the North Sea, including the English Channel, as a Special Area for discharges of garbage. This means that all waste except sewage and food wastes must be returned to shore. Once onshore all these wastes are covered by legislation which controls their handling, transport and ultimate disposal. Figure 2.20. details the fate of wastes returned to shore. The author did not discover any data on the amount of sewage and food wastes discharged into the sea from offshore platforms. It may be assumed that one person produces $0.1m^3$ of sewage (100g faecal matter & 10g of urea) and $0.2m^3$ of water use contaminated with traces of oils and soaps. It is assumed that 100 people are present on a facility, $30m^3$ of sewage will be discharged with Biological Oxygen Demand (BOD) of 300g per m^3. A BOD of 9 kg per day (3.3 tonnes per year) can be expected. In the Central and Northern North Sea there are 18,500 people working offshore (Aberdeen City Council, 1999).

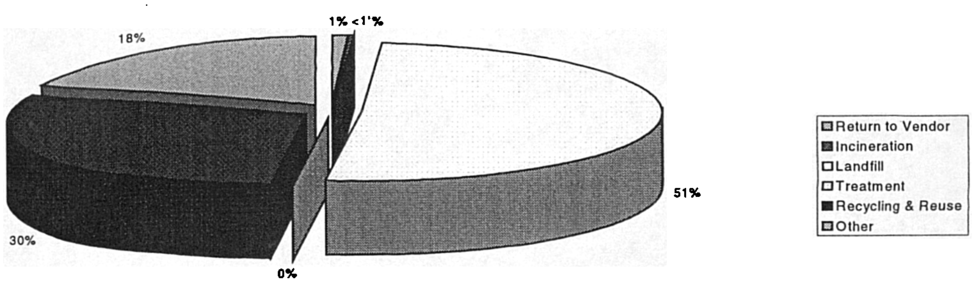


Figure 2.20. Fate of Wastes Returned to Shore
Source: UKOOA, 1999

2.5.5.2 *Other*

There are not enough data on underwater noise levels near production platforms for quantitative analysis. From what is known it is predicted that underwater noise levels would be low, steady and not very disturbing. Higher sound levels would be expected from the stand-by supply vessels (Richardson *et al.*, 1995).

2.5.5.3 *Transportation*

The environmental aspects associated with transportation vary with the mode, pipeline or shuttle tanker. The carriage of oil by well-monitored pipelines is favoured over transportation on the sea due to the lower risk they pose to the environment. Tankers cannot be used to transport gas from a gas field unless it can be converted to LPG. The key environmental aspects from pipeline transportation are the pipeline chemicals used for cleaning and testing. The environmental aspects of pipeline transportation are presented in Table 2.15.

Activity	*Environmental Aspect*
ROUTINE	
Pipelay barge presence	Temporary loss of fishing ground access
Mobilisation of vessels	Exhaust atmospheric and bilge water emissions
Pre-sweep dredging	Seabed disturbance
Anchoring	Seabed disturbance
Pipeline positioning on seabed	Seabed disturbance; provision of new substrate
Trenching & backfilling	Seabed disturbance
Rockdumping	Seabed disturbance, acoustic disturbance
Concrete mattress installation	Seabed disturbance
Riser and spool pieces installation	Seabed disturbance
Disposal of pigging wastes	Solid wastes to sea (wax and asphaltenes)
Flooding, hydrotesting and dewatering	Pipeline chemicals to sea
Displacement of conditioning gas	Nitrogen emissions to air
Sacrificial anodes and antifoulant coating	Heavy metals to sea
Inspection, maintenance and repair	Seabed disturbance, bilge water discharges and atmospheric emissions
ACCIDENTAL	
Loss of containment	Release of produced fluids (oil and/or gas)
Mishandling of materials	Dropped objects and spilled chemicals to sea
Vessel collision	Fuel, cargo and chemicals to sea

Table 2.15. Pipeline Transportation and the Environment

Pipelines are cleaned and tested by filling them with a mixture of seawater and chemicals. A dye is added to so that leaks can be detected before oil or gas flows through the line. Other substances are used to prevent corrosion. Under a consent issued by the DTI, the treated seawater may be discharged directly into the sea after the cleaning and commissioning process or, where practicable, it may be processed by the onshore facility. Figure 2.21. highlights that the majority of pipeline chemicals that will be discharged to sea are in the least hazardous OCNS Group E. The loss of contained produced-fluids over a long period of time causing chronic pollution may occur from pipelines that are not well maintained.

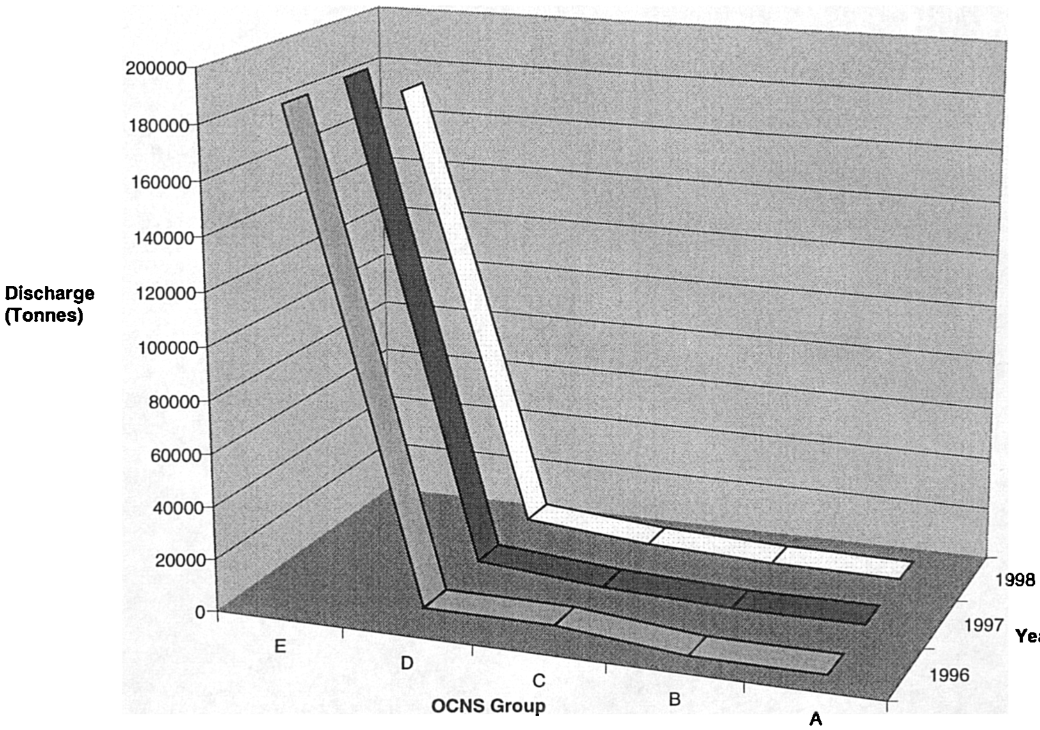


Figure 2.21. OCNS Group Chemicals Discharged to Sea before Pipeline Commissioning
Source: UKOOA, 2000

The author did not discover any environmental appraisal that quantified the environmental aspects from shuttle tanker transportation. Section 2.5.5.1 identifies that offshore loading accounts for a significant proportion of methane emissions. Table 2.16. details the environmental aspects produced by transporting oil from a non-fixed production facility to a shore-based terminal by shuttle tanker.

Activity	*Environmental Aspect*
ROUTINE	
Power generation for transportation	Combustion Emissions to air
Ballast and bilge water discharges	Oil and chemical discharges to sea
Loading and offloading of oil	Venting of VOCs and oil spillage
Waste Disposal	Garbage and sewage wastes
ACCIDENTAL	
Collision, grounding, foundering and fire/explosion	Release of oil products to air, land and/or sea
Venting and fugitive emissions	Release of oil products into the atmosphere

Table 2.16. Shuttle Tanker and the Environment

2.6 DECOMMISSIONING

There are more than 7000 offshore structures in 53 different countries (Stephenson, 1999). The majority (over 4000) are located in the Gulf of Mexico, of which 90% are located in shallow water of less than 75 m and thus have to be removed in accordance with International Maritime Organisation (IMO) regulations as they pose a risk to navigation. The North Sea contains the biggest concentration of large installations worldwide. The distribution of installation sizes and types is shown in Table 2.17.

Country	***Fixed Jackets***		***Gravity Base Structures***	***Floating Installations***	***Jack-ups***	***Subsea***
	< 4k te & < 75 m depth of water	**> 4k te & > 75 m depth of water**				
UK	125	65	9	9	2	36
Norway	19	25	15	4	0	11
Netherlands	61	1	1	0	0	3
Denmark	25	1	0	0	0	1
Ireland	0	2	0	0	0	0
Total	230	94	25	13	2	51

Table 2.17. Distribution of Installation Sizes and Types in the North Sea
Source: Coleman, 1997

The Northeast Atlantic is controlled by legislation in addition to IMO's Regulations – OSPAR Decision 98/3. The UK is a party to the Convention under which the law has become legally binding. There are some salient requirements of the Decision:

- It states that all new steel platforms placed on the seabed after 9 February 1999 must be removed entirely.
- Large concrete installations may remain. New concrete installations will not be allowed unless they are required for safety or technical reasons.
- All steel platforms require complete removal unless the weight of the jacket is greater than 10,000 te whereby the base of the jacket may be left in place if removal is unacceptable on safety, environment, technical or financial grounds and after consultation with the OSPAR states.

The Decision is also discussed in section 3.4.3. Thus there is only one offshore technical option for installations with a jacket of 10,000 tonnes or less and that is to remove topsides, whole substructure, wells and piles to 5m below seabed for reuse, or recycling, or final disposal on land. The exemptions to prohibitions are detailed in Annex X of the Decision (OSPAR, 1998a). However, for installations over this threshold and where an alternative disposal other than complete reuse, or recycling, or final disposal on land has been agreed with the DTI (in the form of a permit) the offshore decommissioning options include:

- Do nothing (i.e. except navigational lights and buoys)
- Partial on-shore disposal, re-use or recycling - remove topsides to shore or remove topsides and part of substructure
- Remove topsides and whole substructure and convert to artificial reef (fishery aggregating device)
- Emplacement/toppling on site
- Deep sea disposal
- Innovative uses (creation of artificial reefs and havens, offshore fish farming; wind and wave power generation; military usage; navigational aid; meterological research; and oceanographical research).

The peak years of decommissioning are forecasted to occur between 2005 and 2010. It is expected that at this time 32 oil and gas platforms will be decommissioned. The total estimated cost of decommissioning platforms on the UKCS is £12 bn, half of which will be paid for by half the North Sea's major players including Shell, BP and ExxonMobil (Euroil, 1998). The financial burden is reduced by changes to the UK tax regime, which puts part of the cost onto the UK taxpayer. The regime permits a decommissioning allowance that gives 100% relief against corporation tax for decommissioning costs. Operators have also allocated special funds for decommissioning (Euroil, 1998). Offshore there are four basic classes of installation that require decommissioning:

- fixed platforms
- moored or tethered platforms
- pipelines
- subsea structures.

2.6.1 Fixed Structures

Pile Support Jackets and Concrete Gravity Structures (CGS) (also known as Gravity Based Structures (GBS)) represent the greatest risks to an operator. The topsides of fixed structures are either modular packages of 500 to 3000 tonnes dry weight stacked on plate girder Module Support Frames (MSFs) or Super Module Packages of 3000 to 5000 tonnes placed upon Integrated Deck Structures of up to 9500 tonnes. The former configuration is to be found on the older platforms and the latter on newer platforms.

CGSs are far fewer in number but are of one or two orders of magnitude heavier than their depth-equivalent steel jacket neighbours. They present difficulties for decommissioning and removal. As for steel jacket platforms, the removal of topsides can be achieved using semi-submersible crane vessels (SSCVs) and very large semi-submersible crane vessels (VLSSCVs). The MSFs are installed on the concrete substructure by floating them over support barges as they are generally beyond the lift capacity of even the largest VLSSCV.

2.6.2 Moored or Tethered Structures

Tension Leg Platforms (TLP), Floating Production Systems, Floating Production Storage and Offtake Systems (FPSOs), Spar buoys and Articulated Towers are all examples of moored or tethered structures. All are vessel based. Operational safety and maintenance requirements result in mooring lines and tethers being capable of ready disconnection both from the vessel and from seabed anchor points. Similarly, flexible flowlines and risers are capable of ready disconnection and retrievable. For these reasons such structures are, by comparison to fixed structures, easily decommissioned offshore and towed ashore. Large FPSOs will only be able to gain access to major dry (graving) dock facilities for decommissioning.

2.6.3 Pipelines

The production section details the types of pipelines that occur on the UKCS. Pipeline decommissioning is outwith the scope of OSPAR Decision 98/3. Industry has developed three guiding principles:

- Decisions on a case by case basis
- Total or partial removal should not affect the marine environment
- When a pipeline is left in place, due regard must be paid to the rate of deterioration of the material and its impact on the marine environment.

Pipelines are extensively used in the North Sea to transport oil and gas. Table 2.18. details the length of pipeline in the UK North Sea.

Outside diameter (inches)	<6	6-9	10-19	20-29	>30
Length (km)	1,360	815	2,193	3,026	2,476

Table 2.18. Length of pipelines in the UK North Sea, 1995
Source: Auris Environmental, 1995

Their technical decommissioning options are:

- remove from seabed and transport to shore

- bury by retrenching or by rock dumping
- part removal
- leave in place.

Pipelines may be removed by a reverse lay process using semi-submersible lay barges or by cutting pipelines on the seabed and removing by lifting appropriate segment lengths. Where pipelines have been successfully buried, either by trenching or by covering, and have remained buried there, it would appear to be unnecessary to attempt removal. Removal could be justified where such pipelines had become exposed and their long term stability could not be assured.

2.6.4 Subsea Structures

These structures range from guide bases for exploration wells, to multiple wellhead templates and production manifolds. These may be removed with existing cutting technology and relatively small lifting vessels in shallow and medium operating depths. In deep waters, beyond commercial diver intervention, subsea units are designed so that the installation process is mechanically reversible e.g. BP's Foinaven Field west of Shetland (BP Exploration, 1995). Only if such equipment or procedures failed irreversibly would it be necessary to seek approval to abandon the equipment on the seabed.

2.6.5 Environmental Conditions

Decommissioning, by its very nature, is a clean-up procedure restoring the environment to its former condition. However the activity poses risk to the environment. Figure 2.22. simplifies the process and its interaction with environment. Decommissioning aims to restore the environment to its former quality.

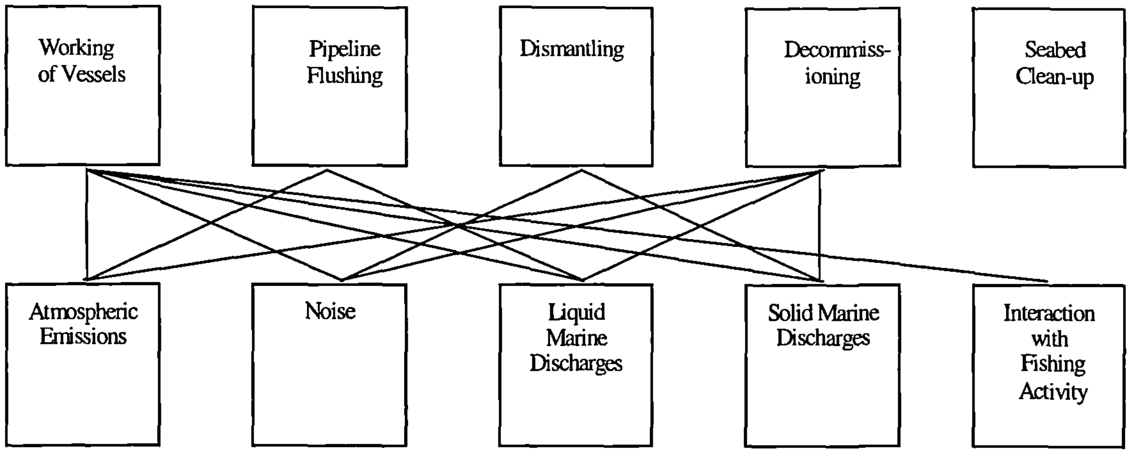


Figure 2.22. Decommissioning and the Environment

The severity of impact will vary according to the type of platform to be decommissioned, and the disposal option. The environmental aspects associated with decommissioning platforms are detailed in Table 2.19.

ACTIVITY	*ENVIRONMENTAL ASPECT*
ROUTINE	
Mobilisation , working and demobilisation of vessels at site	Exhaust emissions; discharges to sea; acoustic disturbance Loss of access to fishstocks
Pipeline flushing	Discharge of chemicals to sea; gas to air
Concrete mattress placement and/or sandbags over cut ends of pipelines	Seabed disturbance
Dismantling, Topsides, Jacket and Footings	Seabed and acoustic disturbance; shock waves if explosives used
Mechanically cutting off well casing below the seabed	Metal emissions
Retrieval of casing	Seabed disturbance
Mechanically cutting through piles below the seabed	Metal emissions
Transporting all recovered material to shore	Exhaust emissions; bilge water to sea
Dismantling structures at the onshore receiving site (mechanical cutting and removal of biofouling material)	Solid waste (mud cuttings; processed concrete and ballast material), Gaseous emissions, Contaminated drainage, Noise, Nuisance, Ground vibration, Dust ,Odour, Light*
Recycling of materials	Atmospheric Emissions Chemical Discharges into inland waterways and coastal waters
Post decommissioning seabed clearance by trawling	Seabed disturbance
Landfill disposal	Atmospheric emissions
Landfarming	Cuttings; Odour
ACCIDENTAL	
Mishandling of materials	Oil, chemicals and persistent waste to sea, land and air
Leakage from abandoned wells	Oil
Failure of structural integrity during decommissioning	SAFETY, Oil, chemicals and persistent waste to sea, land and air, seabed disturbance
* light pollution from floodlights whilst working at night	

Table 2.19. Decommissioning Activities and their Environmental Aspects

There are concerns about the technical feasibility of de-ballasting and disengaging CGSs from the seabed and maintaining the structural integrity during these processes. Environmental risks exist in the possible release of residual oil, slops and sludge from the storage facilities during partial demolition or toppling the shaft using explosives. The shock waves generated will have a serious adverse, even fatal, effect on fish and mammals. Significant volumes of trapped hydrocarbons may still remain after cleaning by purging and flushing with surfactants. Even if deep sea dumping was permitted, it is probably the case that large CGS platforms could not be removed practicably, safely and with maintained structural integrity (Meenan, 1998).

2.6.5.1 Disposal Options

Re-use, recycle or dispose of on land whenever and wherever possible are the major and preferred disposal requirements under OSPAR Decision 98/3. The industry commissioned an environmental assessment of decommissioning UK oil and gas platforms (the Auris Report). The study estimates the quantities of materials to be found on offshore platforms in the North Sea. These are reproduced in Table 2.20.

Material	*Typical types and applications*	*Total tonnage on North Sea platforms (te x 10^3)*
Aluminum	Structural grades; helidecks; bridges; living quarters; fire and blast walls; cladding and walkways; anodes (aluminium-zinc-idium alloys	208
Carbon steel	Jacket structures; decks; module frameworks; stairways; walkways, piping, risers, caissons	3,078
Concrete (structural)	Structure of GBS platforms; foundations of TLPs and jack-up platforms	3,220
Concrete (non-structural)	Fireproofing; grout for conductors and piles	410
Copper	Cupro-nickel; brass; bronze - seawater piping; pumps; cladding; cables	212
Halons	Gases for firefighting and refrigerants	0.5
Lead	Batteries and paint	2.2
Mineral wool	Rockwool and asbestos for fireproofing and insulation	19
Naturally occurring radioactive material	Low activity specific activity scale in pipework	5
Other non-ferrous	Titanium - piping; risers; heat exchangers; nickel alloys; piping	nq
Plastics	Composites - piping; caissons; living quarters; fire protection; walkways; stairways coatings, linings and architectural fittings	37
Reinforcing steel	In concrete structures	411
Residual process oils	Liquids bearing oils or process fluids which have been produced as a result of final flushing out operations	56
Rubber	Hoses; seals; coatings and flex joints	17
Stainless steel	316 grades; 6 molydenum grades ; duplex grades - piping; vessels; heat exchangers and cladding	223
Wood	Architectural fittings	2
Zinc	Anodes; galvanised coatings; paint	12

Table 2.20. Materials to be found on Offshore Installations
Source: Auris Environmental, 1995

As detailed earlier, alternative disposal options require a permit from the DTI. Any derogation from the preferred disposal options will become increasingly difficult with time (Fitzgerald J, 1999). A facility's principal plant and materials for re-use, recycle or onshore disposal are detailed in Table 2.21.

Hazardous Materials	*Valuable Materials*	*Reconditionable Plant*	*Wastes*

LSA Scale Heavy Metal Sludge PCB Fluids Halon Gases Asbestos Contaminated materials Stored Oil Oily Cuttings	Titanium Stainless Steel Cunifer Monel	Prime Movers Rotating Equipment Injection Pumps Compressors Gas Turbines Alternators MV/HV Transformers	Marine Growth

Table 2.21. Facility Plant and Materials for Reuse, Recycle or Onshore Disposal
Adapted from Meenan (1998) & Stephenson (1999)

It is unlikely that the same operator will re-use a facility unless it has knowledge of the parameters of the next field to be developed and that these are similar to the existing field about to be decommissioned. The re-use market shows little interest until a suitable and sizeable stock of equipment is available (Stephenson, 1999). There are specialist companies in the UK that are able to store such equipment for future buyers. Where subsea wellheads and production manifolds are designed to high specifications, with corrosion resistant materials and are deployed for a short production life, re-use becomes a safe and economical option. CGS and fixed major platform structures will be well through their original design fatigue lives and will be characterised by significant loss due to corrosion. It should be noted that the re-use of such equipment, which is beyond its working life, is not safe and it should be sold for scrap.

3 Environmental Performance Challenges to Offshore Oil and Gas Field Development Planning and Management

3.1. *SUMMARY*

Reducing the environmental impact of offshore operations is one of the most pressing challenges facing the oil and gas industry in Europe today. A study was conducted to review the issues by literature search, and consultation with stakeholders and experts. It was clear from the literature search that considerable research had been dedicated to: protecting the marine environment; achieving compliance with legislative controls; assessing the technical and economic feasibility of platform disposal options; and ecological surveying. By comparison, considerably less research had been carried out in other important areas such as: assessing the impacts wastes returned to shore for disposal; identifying sustainable strategies for operations; and assessing and mitigating against adverse impacts from atmospheric emissions. It is clear that the environmental regulatory regime offshore will become tougher and have an increasing influence on offshore oil and gas field environmental planning and management. Future regulatory developments include: a streamlining of the offshore oil and gas environmental regulatory regime; the introduction of the Habitats Directive into the licensing system; and the Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 1999. In addition, post Kyoto regulatory developments and societal concern over atmospheric pollution, will increasingly focus efforts on reducing the emission of global warming gases. These changes coupled with the uncertainty over how resilient the environment is to perturbation presents a need to clearly manage environmental information.

3.2. *INTRODUCTION*

The purpose of this chapter is to review environmental issues that are presenting, and will present, challenges to future offshore oil and gas environmental planning and management. Oil production accounts for 35% of the world's commercial energy supply, while natural gas accounts for 23%. Of this total production, approximately 25% of the gas and 20% of the oil is currently being produced from offshore fields.

In the UK, 23 billion 'barrels of oil equivalent' (boe) has been produced from offshore fields since 1975, with an estimated 20 billion boe remaining. Oil and gas provide 69% of the UK's energy needs (oil = 36%, gas = 33%) and contributes to some 2% of the UK's Gross Domestic Product (Department of Trade and Industry, 1998a).

World carbon emissions have increased nearly four-fold since 1950. The annual emission of carbon from the burning of fossil fuels rose 107 million tonnes in 1997 to a new high of 6.3 billion tonnes. The 1.5% increase on 1996 was due to continued emissions growth in the industrial and developing worlds (Worldwatch Institute, 1998). This increase in carbon emission coupled with a 1997 record high for global temperature is focusing attention on global warming.

Against a range of familiar global environmental issues, the oil and gas activity in the UK sector of the North-East Atlantic has attracted considerable attention in recent years. This has been reflected in an increase in public concern, environmental research and legislation. The study, which is presented in this paper, addresses some of these changes.

3.3. SOURCES OF INFORMATION REGARDING ENVIRONMENTAL LEGISLATION AND ASSOCIATED RESEARCH

This review of the current environmental challenges facing the oil and gas industry in the North-East Atlantic involved the following activities: Literature Search; Consultation with Stakeholders; and Consultation with Experts.

3.3.1 Literature Search

A literature search of public domain scientific and engineering research papers and industry reports was conducted. The search criteria included all literature that was directly relevant to the UK Offshore Oil and Gas Industry from 1990 onwards i.e. UK, European and relevant international literature. The search concentrated on the impact that the offshore industry has on the environment and the measures that it was employing to mitigate against significant adverse environmental impacts.

3.3.1.1 Databases

The databases searched included: Abstracts in New Technology and Engineering; Applied Science and Technology Index; Aquatic Sciences and Fisheries Abstracts; Barbour Index; Bath Information and Data Services - Science Citation Index; Econlit;

Environment Abstracts; Environmental Data Services; Petroleum Abstracts; Society of Petroleum Engineers Abstracts; and Water Resources Abstracts.

3.3.1.2 Search Method

The subject categorisation system shown in Table 3.1 was developed and modified as required during the search. Most of the subject categories were taken from those used by the Offshore Engineering Information Service (Heriot-Watt University) and the Institute of Environmental Assessment (IEA) membership form. At the time of writing, environmental performance reports were available from 55% of the 33 oil and gas companies which are members of the UK Offshore Operators Association (UKOOA). The literature search did not include these reports nor field development Environmental Statements (ESs). Although an increasing number of Environmental Statements is being produced these are relatively new (from mid-1998 onwards) and can suffer from bias inherent in the fact that the responsibility for ES production under UK legislation rests with the developer. Operator environmental performance reports are also new and there is yet no standardised format for environmental reporting in the UK. Thus they contain both qualitative and quantitative data that varies considerably between operators. However, such evolving practice data offers further sources of useful information for future analysis, beyond the scope of the current review.

3.3.1.3 Results

There were 1516 publications and papers which fell within the categories detailed above. The number of papers and publications relating to a specific research field was expressed as a percentage of the total number. Those fields that had less than 5% of the total number were classified as areas of low research priority in the UK. Research fields between 5-50% represent a medium level of research priority and above 50% as a high research priority. The results of the literature search are presented in Table 3.1. This highlights the dominant areas of environmental research associated with the oil and gas industry.

Subject Category	*Number of Citations*	*%*	*Research Priority*
Marine discharges	793	52	High (>50%)
Environmental regulation (of which environmental planning and assessment)	250 (44)	16 (3)	Medium (5-50%)
Decommissioning and abandonment	130	9	
Environmental protection (of which environmentally sensitive areas)	83 (10)	5 (1)	
Environmental management systems and auditing	63	4	Low (<5%)
Environmental risk assessment	58	4	
Waste management	58	4	
Environmental economics	52	3	
Atmospheric emissions	22	1	
Sustainable development	7	negligible	
Total	1516	100	

Table 3.1. Results from Literature Search

During the above search, a considerable number of references to scientific research into the global impact of burning fossil fuels were found. However, the research did not evaluate the global impact of burning oil and gas during offshore oil and gas operations in the UK. It was therefore not included in the study.

3.3.2 Consultation with Stakeholders

To ensure that the search for emerging issues and gaps in the current state of knowledge was comprehensive, the organisations listed in Table 3.2 were consulted by personal communication. All responses involved qualitative opinion and recommendations of publicly available information about their roles with the offshore oil and gas industry. Such material was obtained where it was considered that greater clarification was required on an organisation's level of involvement. An operator consults many of these organisations to assess the environmental impact of a proposed field development.

Statutory Organisations	Non-Statutory
Countryside Council for Wales	Advisory Committee on Protection of the Sea
Department of Environment for Northern Ireland	Association of Scottish Shellfish Growers
Department of the Environment, Transport and the Regions (including the Marine and Coastguard Agency)	British Oil Spill Control Association
Department of Trade and Industry	Exploration and Production Forum
English Nature	Greenpeace
Environment Agency	Institute of Environmental Assessment
Joint Nature Conservation Committee	International Petroleum Industry Environmental Conservation Association
Ministry for Agriculture, Fisheries and Food (including The Centre for Environment, Fisheries and Aquaculture Science)	International Union of Air Pollution Prevention and Environmental Protection
Offshore Safety Division of the Health and Safety Executive	Lloyd's Register Offshore Division
Scottish Environmental Protection Agency	Marine Conservation Society
Scottish Natural Heritage	National Society for Clean Air and Environmental Protection
Scottish Executive Rural Affairs Department	Natural Environment Research Council (including the Sea Mammal Research Unit)
	Oil Companies International Marine Forum
	Royal Society for the Protection of Birds
	Scottish Association for Marine Science
	Scottish Fishermen's Federation
	Scottish Salmon Growers' Association
	Shetland Salmon Farmers' Association
	The Centre for Marine and Petroleum Technology
	The Joint Links' Oil and Gas Environmental Consortium
	The Whale and Dolphin Conservation Society
	United Kingdom Offshore Operators Association
	World Wide Fund for Nature

Table 3.2. Statutory and Non-statutory Organisations with Direct and Indirect Involvement with the Offshore Oil and Gas Industry

3.3.3 Consultation with Experts

A number of conferences specifically associated with key environmental issues of interest to the oil and gas industry have recently been held. By attending conferences, monitoring topics presented, and interviewing speakers, a clear understanding was obtained of the breadth of issues that affect industry. The following conferences were attended: Offshore Europe '97 (an Oil and Gas Exhibition and Conference), Aberdeen; Shell UK Environment Day, Aberdeen; Technology, the Environment and Us - Interdisciplinary Research Network on the Environment and Society, Imperial College, London; Marine Conservation Society Annual Conference, Warwick; Meeting Environmental Standards for the Offshore Industry, International Business

Communications UK Conferences, Aberdeen; the Practicalities of Implementing an Offshore Environmental Impact Assessment, Institute for International Research, Aberdeen; and the first Atlantic Frontier Environmental Forum meeting, Aberdeen.

3.4. ANALAYSIS OF CURRENT AND FUTURE ENVIRONMENTAL CHALLENGES

3.4.1 Environmental Regulation

Companies exploring and developing the UK's oil and gas resources are subject to a balanced regime of environmental regulation from national, European and international laws and self-regulation. The Department of Trade and Industry's (DTI) Oil and Gas Directorate regulate the offshore oil and gas industry using a licensing system with conditions, restrictions and petroleum operations notices. The DTI consults and continues to consult the industry, environmental experts from other Government Departments, Statutory Agencies and Non-Governmental Organisations, such as conservation bodies, when developing this licensing system.

3.4.1.1 Overview of Environmental Legislation

At the beginning of 1999, there were over 300 environmental EU Directives and according to Department of the Environment, Transport and the Regions officials the number of statutes and statutory instruments runs into the thousands (Moore, 1999). A broad overview of the environmental legislation that is relevant to the activities of the offshore oil and gas industry in the UK is detailed in the Table 3.3.

Marine Environment	The Atmosphere
Treaties & Conventions	
The 1972 London Dumping Convention and the 1996 Protocol to that Convention The 1982 UN Convention on the Law of the Sea (acceded by the UK in 1997) International Convention for the Prevention of Pollution from Ships 1973 and the 1978 Protocol to that Convention (MARPOL 73/78) The 1983 Bonn Agreement The 1990 Convention on Oil Pollution Preparedness, Response and Co-operation Agenda 21, an Action Plan for the Next Century, 1992* The 1992 OSPAR Convention The 1992 Convention on Biological Diversity The 1994 Energy Charter Treaty	UN Framework Convention on Climate Change 1992 The UN Economic Commission for Europe Long Range Transboundary Convention, Protocols on VOCs (1991), NOx (1988), SOx (1994) The Montreal Protocol 1989, amended in 1992 Agenda 21, an Action Plan for the Next Century, 1992* The Kyoto Protocol 1997
UK legislation, strategies and programmes	
Prevention of Oil Pollution Act 1971, as amended by the Merchant Shipping Act 1995 The Control of Pollution Act 1974 The Wildlife and Countryside Act 1981 Food and Environmental Protection Act 1985 Water Resources Act 1991 Radioactive Substances Act 1993 (RSA) "Biodiversity: The UK Action Plan", 1994 Conservation (Natural Heritage &c) Regulations 1994 "Sustainable Development: The UK Strategy" 1994 The UK Revised Offshore Chemical Notification Scheme 1996 The Merchant Shipping (Prevention of Oil Pollution) Regulations as amended by the Merchant Shipping (Prevention of Oil Pollution) Regulations 1997 The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998 Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1998 The Petroleum Act 1998 The Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations 1999 "A better quality of life: A strategy for sustainable development for the United Kingdom" 1999	Health and Safety at Work Act 1974 The Energy Act 1976 Integrated Pollution Control (IPC) Regulations (the main outline of IPC is detailed in Part I of the Environmental Protection Act 1990) "Reducing Emissions of Volatile Organic Compounds and Levels of Ground Level Ozone: A UK Strategy" 1994 "Climate Change: The UK Programme" 1997 The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 1999
* Chapters 9 & 17 call upon States to adopt measures to minimise pollution from sea-based activities and to minimise air pollution from the energy sector *Note: This table does not include any legislation covering liability and compensation, or EC environmental law, which is enacted into UK law. The EC has developed an extensive body of environmental law that comprises of more than 250 environmental directives, regulations and decisions, many of which affect the oil and gas industry either directly or indirectly.*	

Table 3.3. International and UK Environmental Legislation, Strategies and Programmes

3.4.1.2 Environmental Legislators and Regulators

The principal organisations involved in the development and implementation of legislation include:

- the United Nations Environmental Programme
- International Maritime Organisation
- the Oslo and Paris Commission for the Protection of the Marine Environment of the North-East Atlantic
- the European Commission Directorate-General (D-G) XI (environment) and D-G XVII (energy)

- UK Government departments; the Department of Trade and Industry, the Department of the Environment, Transport and the Regions, the Scottish Executive Rural Affairs Department, the Ministry of Agriculture, Fisheries and Food, the Scottish Environmental Protection Agency and the Environment Agency

3.4.1.3 UK Exploration and Production Licences

Oil and gas exploration and production regulations made under the Petroleum (Production) Act 1934 have been re-enacted under The Petroleum Act 1998. The Petroleum Act 1998 vests ownership of oil and gas within the United Kingdom and its territorial sea in the Crown, and gives Government the right to grant licences to explore for and exploit these resources. Licences are granted at the discretion of the Secretary of State (SoS) for Trade and Industry. The terms of licences vary according to whether they cover Seaward or Landward areas. There are two types of Seaward licences: Exploration Licences and Production Licenses. The exploration licence allows the operator to carryout seismic survey and other survey work on any part of the UK Continental Shelf not subject to a current production licence. Exploration wells must not exceed 350 metres in depth without the approval of the SoS. The production licence grants exclusive rights to an operator "to search and bore for, and get, petroleum", in a specific block or blocks.

The DTI is required to review applications for both types of licence. Applicants for production licences are expected to submit copies of their company environmental policy, environmental management system and an environmental assessment of the areas applied for, with their applications. They are also expected to demonstrate how environmental considerations are covered in their work programme, supporting their arguments with a proven environmental record.

3.4.1.4 Environmental Assessment

The most significant piece of regulation that has been implemented in recent years is the Offshore Petroleum Production and Pipe-Lines (Assessment of Environmental Effects) Regulations 1999. These regulations are based upon and/were introduced so that UK regulations comply with the EEC Environmental Assessment (EA) Directive (85/337/EEC) and the amended EA Directive (97/11/EC), and were enacted into UK legislation on 14th March 1999. The EEC EA Directive (85/337/EEC) first became law offshore under the Offshore Petroleum Production and Pipe-Lines (Assessment of

Environmental Effects) Regulations 1998, on 30th April 1998. The new regulations require that Environmental Statements (ESs) are prepared for new offshore oil and gas projects that are expected to produce at least 500 tonnes or 500,000 cubic metres of gas per day, and for the installation of offshore pipelines over 800 mm diameter and over 40 km long (Department of Trade and Industry, 1998c). They require an assessment of cumulative effects. They also require the public to be consulted in the preparation of an ES. Prior to the enactment of the EA Directive, public participation was absent from any environmental review in offshore permitting and licensing. The SoS may grant dispensation, if the proposed activity is below specific development thresholds or if the SoS determines that it is not likely to have a significant impact on the environment.

3.4.1.5 Research & Environmental Regulation

The level of research carried out in the area of environmental regulation was significant and was generally focused on: assessments of the impact of legal controls and compliance on planning and development; liability; levels of compensation to other users of the sea; and reviews of emerging legislation, policies and guidelines.

Considerable discussion at industry conferences relates to the issue of what impact the new environmental assessment regulation will have on field development and planning, including the practicalities of implementation, and what needs to be done to ensure that an ES is accepted, and development consent is achieved. One aspect of the assessment process, that conferences are addressing particularly, is 'how to determine the significance of an impact', especially when the value placed on natural resources varies between experts, the government, industry and the public.

3.4.1.6 Developments & Trends

Environmental regulation, in general, is becoming extensively implemented. The Aarhus Convention (the Convention on Access to Information, Public Participation on Decision making and Access to Justice in Environmental Matters) has been recently ratified by Canada, Europe and the US. It will widen the current provisions for access to environmental information and may result in legislation that allows the public to challenge official decisions at European Commission level. Thus the UK environmental agenda is dynamic and in a state of change, but all of the evidence suggests that subsequent environmental legislation will become tougher and have an increasing influence on offshore oil and gas field environmental planning and management.

3.4.2 *Marine Discharges*

Pollution of the marine environment has been the area of greatest environmental concern over the last few decades. For example, in a survey carried out by the Scottish Office to assess the Scottish public's attitudes towards the environment, 'pollution of rivers, lochs and seas' and 'raw sewage into the sea' were the two environmental issues that concerned people the most. The survey addressed 22 environmental issues and rated the response of the public against a "concern index". This index was scaled on the basis of: how serious the issue was considered to be; how personally affected people were; and how worried they were about it (Scottish Office, 1991). The issues were chosen partly on the basis of qualitative work (group discussions) conducted in different parts of Scotland prior to the main survey, and partly from the list of issues used by the Department of the Environment in a 1989 survey (Department of the Environment, 1990). The Department of Environment, Transport and the Regions carried out a similar survey in England and Wales in 1996 and 1997. It too discovered that individuals were primarily concerned about marine pollution (Department of the Environment, Transport and the Regions, 1998a). A more detailed analysis of UK public opinion is considered in section 4.5.4.

3.4.2.1 Oil Spills

Based on data from 1985 to 1990 the offshore oil and gas industry discharged in the range of 20-30 thousand tonnes of oil per year into the North Sea (North Sea Task Force, 1993). This was approximately 20% of the total oil input over that period. Other sources of oil that made up the other 80% were: shipping; dredged spoils; dumped industrial waste; sewage; industrial effluents (including coastal refineries and oil terminals); rivers/land runoff; atmosphere; and natural seeps. Between 1990 and 1997 operational discharges of oil and oil spills combined declined from 17,602 tonnes to 6,632 tonnes respectively, a reduction of over 60% (Department of the Environment, Transport and the Regions, 1998a). This reduction was the result of an increase in the use of water-based muds, enhanced facility drainage systems and improved oil spill contingency planning. This trend continues into 1998, when the total oil discharged fell to 5,829 tonnes, due to oil-based mud drill cuttings not being discharged to sea since 1 January 1997. This improvement in environmental performance has occurred as the number of installations reporting discharged oil and the actual number of reported discharges have increased. It is unfeasible to specify the anthropogenic sources of all chemicals in the sea and hence there is insufficient information to evaluate the total impact of industry's chemical input to the sea.

3.4.2.2 International Marine Pollution Legislation

In 1992, a convention on the Protection of the Marine Environment of the North-East Atlantic was signed by 16 signatories (Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom) in Paris. This convention, which is known as the OSPAR Convention, amalgamates the principles of the 1972 Oslo Convention (on the prevention of pollution by dumping from ships and aircraft) and the 1974 Paris Convention (on the prevention of pollution from land based sources). Prior to 1992, the 1972 and 1974 conventions were the responsibility of the Oslo and Paris Commissions respectively. These officially joined to form the Oslo and Paris Commission (OSPARCOM), which is an international organisation under British legislation. The Oslo and Paris Convention has been administered by OSPARCOM since it became law on 25 March 1998. Article 13 of the OSPAR Convention set out a new regime whereby Decisions and Recommendations became legally binding for all signatories. The convention also stipulated that the majority of the Decisions, Recommendations and all 'other agreements' adopted by the two Commissions prior to the convention's implementation remained applicable to the offshore oil and gas industry (OSPAR, 1992). In the UK, the articles of the OSPAR convention are implemented in the form of conditions attached to awarded licences, issued under section 23 of the Prevention of Oil Pollution Act, 1971 and enforced by the Department of Trade & Industry (Department of Trade and Industry, 1996).

The OSPAR Convention establishes standards for an acceptable level of discharge of oil and oil-contaminated waste, chemicals and solid waste into the sea. The UK, as a party to the convention, has a duty to report information to the Workgroup on Sea-based Activities (SEBA) on offshore discharges each year, two years in arrears. The regulations regarding the discharge of drilled material, contaminated by oil, into the sea were first introduced in the Paris Commission (PARCOM) Decision 92/2. This decision required that the proportion of oil on dry cuttings should not exceed 10g oil/kg dry cuttings. Since it is not yet technically feasible to reduce the oil on cuttings to this level, oil contaminated cuttings have been disposed of either on shore or by high pressure injection into formations below the sea bed since 1 January 1997. Industry is undertaking research into alternative methods for disposing of cuttings such as: cuttings re-injection; landfill disposal after chemical or thermal treatment; and biodegradation by land farming. One of the main reactions to this pressure on the use of oil based drilling fluid was, and has been, to increase the use of water based drilling fluids.

The main OSPAR recommendation related to the disposal of fluids contaminated with oil was made in the PARCOM Recommendation, Madrid, 1986. A discharge limit of 40 mg/l oil in water for production and displacement fluids was recommended. This low level of contamination is very difficult to achieve and considerable research has been undertaken into assessing the impacts of produced water from maturing North Sea fields and ways in which the total discharge can be reduced through alternative disposal methods such as produced water re-injection.

3.4.2.3 UK Marine Pollution Law

In April 1996, the UK acceded to the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC). OPRC formally requires contracting parties to develop contingency plans to reduce and combat oil spillage. Under The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998 and therefore the terms of the UK offshore block licensing system, an oil spill contingency plan must be made available to the DTI and the Marine and Coastguard Agency, for approval two months before drilling begins. Under these regulations, Her Majesty's Coastguard and the DTI are immediately notified of any event involving a discharge of oil to sea.

The drainage of oil from a facility is also a source of marine pollution. Since the 6 July 1998, a threshold of 15-ppm oil in water for platform drainage has been in force under the Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997. This pre-empted the setting of the same discharge standard under MARPOL (International Convention for the Prevention of Pollution form Ships (1973), as amended by the Protocol of 1978) Annex 1. In a meeting in April, 1998 the Marine Environment

Protection Committee of the International Maritime Organisation designated the seas around the UK and Northwest European coastlines as a MARPOL Annex I special area, which prohibits discharges of oil from shipping (Department of the Environment, Transport and the Regions, 1998b). The convention entered into force on 1st August 1999 and requires that platform drainage discharges must not exceed 15-ppm oil in water (International Maritime Organisation, 1997).

3.4.2.4 Voluntary Controls

Discharges of chemicals into the marine environment are regulated by the DTI using a voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF). The HOCNF standardises the requirements for the testing and reporting of all chemicals used by operators throughout the entire North-East Atlantic Sector. Chemicals are classified into hazard groups (A-E), and operators are obliged to notify the Government if the tonnage limit of a particular group per well drilled will be exceeded. Chemicals in Group A are considered particularly hazardous to the marine environment and their use is strongly discouraged by the Government (Department of Trade and Industry, 1996).

3.4.2.5 Research & Marine Discharges

The greatest amount of environmental research associated with the offshore oil and gas industry has been related to 'Marine discharges'. The studies carried out in this area have included assessments of the effects of oil spillage from operational and transportation accidents, spillage clean-up and waste disposal methods. A collaborative research programme, between industry, the DTI and academia, aimed at assessing sea bed processes and impact appraisal and to ensure improved management of chemical discharges, called 'Managing the Impacts on the Marine Environment', is being directed by Marinetech South Ltd.

3.4.2.6 Developments & Trends

The future regulations controlling the levels of discharges into the sea will become more rigorous. It was agreed at the Ministerial Meeting of the OSPAR Commission, in Sintra (22-23 July 1998) that contracting parties to the OSPAR Convention will strive to achieve a cessation of discharges, emissions and losses of hazardous substances by the year 2020 (OSPAR, 1998a). In February of 1999 the OSPAR's Working Group on Sea-based Activities (SEBA) met to prepare a draft strategy on reducing the discharge of hazardous substances and consider how to implement a 'close to zero' policy and whether it is technically feasible. The report of this meeting is available from OSPARCOM's website and highlights that SEBA is developing a dynamic selection process and prioritisation mechanism to rank hazardous substances according to their environmental risk. The findings of this work will direct the future strategy of OSPARCOM on hazardous substances (SEBA, 1999).

3.4.3 Decommissioning

There are a total number of 400 platforms in the North-East Atlantic, with 234 fixed installations operating on the UK continental shelf (*pers comm.* Health and Safety Executive, 1998). Of these 234, 24 have been decommissioned (11 steel platforms, 4 floating production systems, 3 storage units and 6 subsea installations) (Offshore Decommissioning Communications Project, 1998).

3.4.3.1 International Law on Decommissioning Redundant Oil and Gas Facilities

The UK's international obligations with regard to the decommissioning of offshore installations have their origins in the United Nations Convention on the Law of the Sea of 1982. The Convention entered into force in 1994 and was ratified by the UK in 1997. Article 60(3) includes the following:

"Any installations or structures which are abandoned or disused shall be removed to ensure safety of navigation, taking into account any generally accepted international standards established in this regard by the competent international organisation. Such removal shall also have due regard to fishing, the protection of the marine environment and the rights and duties of other States. Appropriate publicity shall be given to the depth, position and dimensions of any installations or structures not entirely removed."

The competent 'international organisation' referred to in this article is the International Maritime Organisation, which in 1989 developed the IMO Guidelines and Standards, setting out the minimum global standards for the removal of offshore installations. These are voluntary guidelines prepared to ensure safe navigation offshore.

In July 1998 at the first Ministerial meeting of the OSPAR Commission a regime for the disposal of disused offshore installations was established. This regime was based upon the framework developed at the Convention on the Protection of the Marine Environment of the North East Atlantic ('the OSPAR Convention'). Ministers adopted a binding Decision (OSPAR Decision 98/3) to ban the disposal of offshore installations at sea. This legislation states that the dumping, whole or partial abandonment of disused installations in the North Atlantic is prohibited. Reuse, recycling or final disposal on land is encouraged, but exemptions may occur (excluding topsides) for: a steel installation weighing more than 10,000 tonnes in air; gravity based concrete installations; floating concrete installations; and concrete anchor bases (OSPAR, 1998b). This replaced Decision 95/1 of the Oslo Commission concerning the Disposal of Offshore Installations. It is absolute and does not promote a case by case review. The legislation will be reviewed at the next Ministerial Meeting in 2003. It is worth noting that pipelines are not covered by OSPAR Decision 98/3 and there are no international guidelines on the decommissioning of disused pipelines.

3.4.3.2 UK Law on Decommissioning Redundant Oil and Gas Facilities

Until recently the decommissioning of offshore oil and gas installations and pipelines on the United Kingdom Continental Shelf (UKCS) was controlled through the Petroleum Act 1987. However, the decommissioning provisions of the 1987 Act have been consolidated, with other petroleum legislation, into the Petroleum Act 1998. The DTI is the competent authority on the decommissioning and disposing of offshore oil and gas installations in the UK. Section 29 of the 1998 Act enables the Secretary of State to serve notices requiring the recipient to submit a costed decommissioning programme for his approval at such future time as he may direct. The programme (referred to in the 1998 Act as an "abandonment programme") should contain the measures proposed to be taken in connection with the decommissioning of an installation or pipeline (Department of Trade and Industry, 1999b).

Conferences are and have been exploring the implications of this prohibition, ever since the UK Government announced their 'presumption against' sea disposal of redundant oil and gas installations in September 1997 (Environmental Data Services, 1997).

3.4.3.3 Research & Decommissioning

In anticipation of legislation such as that described above, a significant level of research has been undertaken in this area. It included: identifying technical options of disposal (including reusing and recycling) and assessing their feasibility; valuing options; assessing risk to safety; and assessing the impact of decommissioning on the environment.

3.4.3.4 Developments & Trends

Operators designing new fields will be following a complete removal policy, but those with older and larger installations will have to assess their decommissioning options.

3.4.4 Environmental Protection

3.4.4.1 Natura 2000

Environmental Protection is chiefly guided by the EU Habitats Directive - Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, and the Birds Directive - Council Directive 79/409/EEC on the conservation of wild birds. Both are enacted into UK law by the Conservation (Natural Habitats, &c.) Regulations 1994 and the Conservation (Natural Habitats, &c.) (Northern Ireland) Regulations 1995. The legislation aims to provide a network of protected areas across the European Community known as Natura 2000. This network includes Special Protection Areas (SPAs) classified under the Birds Directive and candidate Special Areas of Conservation (SACs) introduced by the Habitats Directive (Scottish Natural Heritage, 1995). The sites relevant to industry are those on the UK coast. The DTI complies with this regulation as the competent authority on offshore licensing, initially by consulting the Joint Nature Conservation Committee (JNCC) (the government's statutory adviser on nature conservation matters) before acreage is offered for licensing. JNCC advises on whether exploration or production activities under a licence would be likely to have significant effects on SPAs or candidate SACs. It may advise that certain blocks are not offered for licensing or that conditions should be attached to others to protect particular sensitivities. UKOOA has developed guidance on developing marine resources in sensitive and near shore areas (UK Offshore Operators Association, 1995).

3.4.4.2 *Operating in Environmentally Sensitive Areas*

The International Petroleum Industry Environmental Conservation Association (IPIECA) and the Exploration and Production (E&P) Forum have developed a case by case history of oil and gas industry operations in sensitive areas. In the UK these include the Forth Estuary, Liverpool Bay, Wytch Farm, Fawley saltmarsh and the Atlantic Margin (IPIECA & E&P Forum 1997).

Offshore baseline ecological surveys provide essential information on the local environment and any potential aspects of the environment that will be sensitive to oil and gas operations. Such information is required in an Environmental Statement. The Department of Trade and Industry requires Environmental Statements when assessing production licence applications. There have been a number of surveys carried out in the waters and on remote islands off the Northwest coast of Scotland over the last three years. The largest being a survey of 20,000 sq km lying west of the Western Isles, covering the acreage of the UK Atlantic Margin which had been licensed for offshore oil and gas production before 1995. These surveys were proactively carried out by the Atlantic Frontier Environmental Network (AFEN). AFEN is an industry-working group, providing a wealth of data for the preparation of future Environmental Statements and scientific papers.

3.4.4.3 *Research & Environmental Protection*

The majority of research in this area is predominantly generic. Research includes: identifying environmentally sensitive areas; determining the state of the environment, and what measures could be and are being taken to protect it; assessments of the impacts of seismic surveys on marine fauna; and environmental toxicological analyses of chemicals used by the industry.

3.4.4.4 *Developments & Trends*

The DTI has proposed the introduction of new regulations, which will implement the Habitats Directive into the offshore oil and gas licensing system. These regulations were expected in late 1998 (Harding, 1998) but are not yet complete. Although the Habitats Directive is primarily of contextual relevance to offshore exploration and production, it is likely to increase pressures to ban or, at least, subject the industry to more stringent conditions in sensitive areas. Further developments following a High Court ruling on the implementation of the Habitats Directive offshore is detailed in Section 4.5.3.4.

3.4.5 Environmental Risk Assessment (ERA)

3.4.5.1 Real Risks and Perceived Risks

The Offshore Petroleum Production and Pipe-Lines (Assessment of Environmental Effects) Regulations, 1999 require the identification of any significant environmental impacts from offshore oil and gas activity. Risk assessment is used to identify hazards to the environment, their probability of taking place and to assess their significance. However, the significance of environmental impact is subjective, and so therefore is the risk. Dealing with the public perception of risk may be as important to businesses as the science behind the assessment. This has been exemplified by the Brent Spar Incident (Macilwain, 1996), and the continuing debate in the UK regarding bovine spongiform encephalopathy / Creutzfeldt-Jacob disease (Orszulik, 1997) and the extremely volatile debate on the use of genetically modified organisms in arable farming. Given the importance of public opinion in the licencing process, some operators now screen for risks that are both perceived and actual. Such a screening process is detailed in BP's Schiehallion Environmental Statement (British Petroleum Company, 1997a).

3.4.5.2 Environmental Risk Assessment & Research

There is comparatively little research specifically devoted to this subject area. This is because ERA is integral to other areas such as environmental assessment and oil spill contingency planning. The research that was undertaken was predominantly by industry and presented in engineering journals. It included studies on: the risk posed by accidental oil spills; identifying hazards in exploration and production operations; and on risk reduction. An area that has received little attention is the assessment of environmental risks posed by cumulative effects.

3.4.5.3 Developments & Trends

As discussed above some offshore operators are screening for perceived, as well as actual, environmental risks. This trend will increase as operators act on the 'precautionary principle' discussed in the UK Sustainable Development Strategy, which states that *"when potential damage to the environment is both uncertain and significant, it is necessary to act on the basis of the precautionary principle"* (HM Government, 1994).

3.4.6 Waste Management

The North Sea is classified as a 'special sea area' under Annex V, of MARPOL 73/78. Under the October 1989 amendments to this convention, the discharge of all garbage from an offshore installation is prohibited (except food wastes). Thus the majority of solid waste material from an offshore oil and gas facility is returned to shore for disposal.

3.4.6.1 Waste Streams

Waste includes: non-hazardous or general waste which is disposed of in general landfill; hazardous wastes for specialised disposal; and bulk returned for treatment or re-use. Offshore oil and gas company environmental reports detail statistics on waste streams and about 2% of the waste material returned to shore from offshore installations is hazardous, (UK Offshore Operators Association, 1997). Environmental audits carried out as part of an EMS, are confidential to operators and were not included in the literature search. However, the environmental management systems (EMS) established by companies operating on the UK continental shelf should promote effective and responsible waste handling and disposal processes.

3.4.6.2 Research & Waste Management

Waste management constituted less than 5% of the research effort identified. This figure may not represent the total amount of research in this area due to its overlap with 'marine discharges' and 'atmospheric emissions'. This research covered issues such as waste management systems, waste disposal options and treatments. With more waste being brought ashore and increasing regulatory controls on the use of landfill sites, industry has begun to carry out research into alternative land based disposal options.

3.4.6.3 Developments and Trends

A draft directive on disposing to landfill was agreed by the European Parliament's Council of Ministers in June 1998. It imposes stringent operational and technical requirements on waste that can be disposed of in landfill and on the operation of the landfill site itself. If it is implemented the UK will be required to significantly reduce the amount of waste going to landfill (Moore, 1999). The costs of disposing to landfill will increase if this landfill directive is implemented.

3.4.7 Environmental Management Systems and Auditing

3.4.7.1 UK Legal Requirements

The Offshore Petroleum Production and Pipe-Lines (Assessment of Environmental Effects) Regulations, 1999, require that an 'externally verifiable' environmental management system (EMS) (Department of Trade and Industry, 1998c), is established for the lifetime of the oil or gas field. These regulations require a periodical audit of the EMS to ensure its effectiveness and that any problems encountered when compiling an Environmental Statement are tackled by the EMS (ibid., pp. 10,11). Environmental audits are split into two categories: internal management review, to ensure that the EMS is appropriate to the company; and externally conducted annual environmental audits, to assess the company's environmental performance under the EMS. Internal management reviews tend to be carried out by companies every six months but this time period is not a requirement of an EMS. Consent for a production licence may be refused by the Secretary of State of Trade and Industry if an operator's Environmental Statement (ES) contains no plans for an EMS.

3.4.7.2 The Environment and, Health & Safety

Following the Piper Alpha disaster in 1988, a public enquiry led by Lord Cullen recommended that the responsibility for offshore health and safety be transferred to the Health and Safety Executive and that all health and safety legislation be reviewed and replaced by a goal-setting regime. All the recommendations were implemented and led to the implementation of the Safety Case Regulations 1992. These regulations (enabled by the Offshore Safety Act 1992) require employers to undertake risk assessments for the purpose of identifying the measures needed to prevent or control risks to employees or others, to a level that is as low as reasonably practicable (ALARP). This is the first time that ALARP has actually been used in UK safety law (Whewell, 1998). When undertaking an analysis of all hazards and associated risks posed, it is frequently discovered that health, safety and the environment issues are interrelated. It is because of this that operators have developed Health, Safety and Environment Management (HSEM) Systems (Exploration and Production Forum, 1995). For operators to be members of the UK Offshore Operators Association they must have a HSEM System.

3.4.7.3 Environmental Management System Standards

There are two standards to which an EMS may be prepared for certification: ISO 14001 and the Eco-management and Audit Scheme (EMAS). Both require that an EMS be periodically reviewed. The European Standards Body adopted ISO 14001 and its sister standards, as a European Standard. EMAS was introduced under the authoritative document EC Regulation 1836/93. These European Standards supersede the British Standard 7750, and when, on 31 March 1997, BS7750 was withdrawn those companies certified to BS7750 converted to BS EN ISO 14001 (UK equivalent to ISO 14001). The European Standards Body produced a 'bridging document' in 1997 demonstrating how to progress from ISO 14001 to EMAS, for those companies registered under ISO 14001 and seeking EMAS certification, (Institute of Environmental Management, 1996). Companies certified to ISO 14001 should find that their EMS is complimentary to EMAS. The primary difference between the two standards is that EMAS requires companies to produce an externally verified environmental report on their progress (Department of the Environment, 1997a). EMSs aim to make manufacturing processes more efficient, reduce costs and protect the environment, but there is concern over the amount of administration involved in their implementation.

3.4.7.4 Research

As operators' commercial and confidential documents were not included in the literature search, a low level of research was recorded. The research that was identified included: assessments of environmental audit; identification of environmental performance indicators; and case studies that assess and review the application of environmental management systems.

3.4.7.5 Developments & Trends

Few operators are certified under ISO 14001 or EMAS, as they already have HSEM systems that ensure effective environmental management. However, it is increasingly likely that operators will seek external verification for their existing HSEM systems. Following minor changes, it is possible for the environmental component of such systems to become certified under ISO 14001 or EMAS. Development in this area depends upon the perceived advantage to industry of implementing ISO 14001 or EMAS.

The HSEM systems which operators have implemented set internal environmental performance targets for offshore operations. Performance is measured against environmental indicators, such as – atmospheric emissions, flaring quantity, discharges to sea, waste returned to land, or proportion of recycled waste. Most of the operators publish their environmental performance annually in an environmental report. There are two types of environmental report being produced by UK offshore oil and gas operators: those that aim to quantify environmental performance and benchmark progress on the previous year; and others that merely report qualitatively on progress. Recently there is a trend to produce environmental reports annually. It was only possible for the authors to acquire environmental reports from 55% of UKOOA's 33 members. Independent auditors were asked to verify the environmental data in one third of sampled environmental reports in 1999. A review of auditors' statements identified that there was considerable variation in what was being verified. These reports were either validated to ensure data consistency or to provide an independent opinion on a company's environmental performance and make recommendations. As the verification process is not standardised, an environmental professional does not necessarily conduct it.

3.4.8 Environmental Economics

3.4.8.1 Profitable Environmental Management

There has been concern that environmental regulation reduces a company's competitiveness. Anderson Consulting have carried out the first detailed investigation into the effects of: environmental performance; resource efficiency; regulatory compliance; and new product and service opportunities, on corporate financial performance (Edwards, 1998). It is the first of its kind and concludes that there is no financial penalty for being environmentally proactive. It confirms findings in the US that good environmental performance improves a company's financial performance. There is also a consensus that companies with the expertise to assess the impact of their activities, and the costs associated with mitigating them, are more likely to be able to make financially positive environmental investment decisions than those without. The UK Government has published booklets for companies to demonstrate how they can save money by being environmentally responsible. These include: '*The Environment: A Business Guide*' and '*Winning through: Environment & Business*'.

3.4.8.2 Research

It appears from this search that there is comparatively little environmental economic research undertaken. The majority of studies that are conducted are focused on specific issues such as: the costs of oil spill clean up and mitigation; assessments of the costs of complying with environmental regulations and decommissioning installations onshore. Few studies were available in the public domain that assessed either the economic benefits of improving an oil and gas company's environmental performance or how this may be optimised.

3.4.8.3 Developments & Trends

An area which has been receiving increasing attention over the last five years is the assessment of the impact of the environment agenda on both the company's financial statements and the statutory audit of those statements (Gray, 1995). The World Wide Fund for Nature is funding the Sustainable Economy Unit. This unit is part of the sustainable development charity Forum for the Future to undertake research in 'green' accounting. The researchers are attempting to develop a method of constructing an accounting framework for indicators of sustainability. This is similar to the NAMEA approach (National Accounting Matrix including Environmental Accounts) of the Central Bureau of Statistics in the Netherlands (Simon, 1998).

The Kyoto Protocol has the objective of reducing greenhouse gas emissions from industry and commerce. The UK has agreed legally binding targets to achieve the reductions discussed under 'Atmospheric Emissions'. Emission trading is an economic instrument made available under the Kyoto Protocol to reduce atmospheric emissions. Trading would work, in theory, by allocating permits for certain emission amounts to companies. The value of a permit would be higher than the cost of physically reducing the equivalent amount of gas. Any company achieving lower emissions than it has permits for, could sell (or lease) the permits for which it did not need to other energy users. The UK Government is assessing whether trading is a workable option (Marshall, 1998). BP Amoco has launched an in-house pilot project for trading carbon dioxide emissions. Statoil is considering participating in a group trading system for climate gases since its operations are not extensive enough to support such a system on their own. A global emission trading system has not yet been established. Oslo's Econ centre for economic analyses has predicted that an international trading system would be established by 2005 (Statoil, 1999).

The drive to improve environmental quality by reducing environmental impacts is best represented by referring to the rapid growth in environmental control technologies. This market grew from $295 billion in 1992 to $426 billion in 1997 or 2% of global gross domestic product. Spending may reach $572 billion by 2001 (Worldwatch Institute, 1998).

3.4.9 Atmospheric Emissions

Atmospheric emissions generated by the industry are a result of: site power generation; flaring; venting; fugitive emissions; and fire suppression systems. The main gases emitted include: greenhouse gases - CH_4, CO_2; atmospheric ozone damaging gases - CFCs, HCFCs; ozone forming smog gases - VOCs, NO_x; and acidifying gases - NO_x, SO_2 (UK Offshore Operators Association, 1997).

3.4.9.1 UK Offshore Oil and Gas Atmospheric Pollution Law

It is the responsibility of the Department of Trade and Industry (DTI) to regulate the atmospheric emissions of the offshore oil and gas industry through the licencing system, under The Energy Act 1976. Flaring and venting emission levels, which are technically and economically reasonable, are agreed between the DTI and a licensee (Department of Trade and Industry, 1993). An Environmental Statement prepared by an offshore operator will detail and assess the impact of atmospheric emissions from a proposed field development.

3.4.9.2 The Kyoto Protocol

At the Kyoto Conference (1-11/12/97), the EU agreed to reduce emissions based on a basket of six gases by 8% of 1990 levels by the period 2008 to 2012. The six gases include Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbon (HFC) & Perfluorocarbon (PFC), Sulphur hexafluoride (SF_6). The UK's legally binding target is 12.5% and will be achieved as part of a staged programme aimed at achieving 20% CO_2 savings by 2010, an overall reduction of 36 million tonnes of carbon (Advisory Committee on Business and the Environment, 1998). Although, CO_2 is less potent than other greenhouse gases on an equal mass basis, the quantity of the emissions is so large that it is the main contributor to global warming. The UK contributes about 2% of CO_2 (611 Mt CO_2/167 MtC) to global anthropogenic emissions of CO_2 (22,000-30,000 Mt CO_2/6,000-8,000 MtC) per annum (HM Government, 1997). The offshore oil and gas industry has been estimated to contribute between 2%-5% to UK CO_2 emissions (DETR, 1997b). The other sources of CO_2 emissions in the UK can be seen in Figure 3.1.

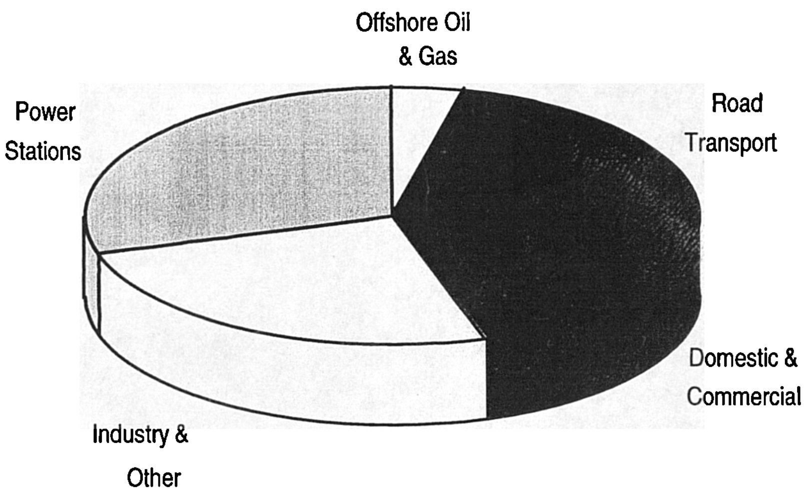


Figure 3.1. 1995 UK and Offshore Carbon Dioxide Emissions
Source: UKOOA (1997), Environment Report

3.4.9.3 UKOOA's Air Emissions Inventory

The DTI's environmental database, 'SCOPEC', collates data on oil and chemical discharges from their Offshore Chemical Notification Scheme. This database does not however include data on atmospheric emissions. The UK Offshore Operators Association (UKOOA) has compiled a database on emissions into the atmosphere. This will be used to provide evidence on reductions in emissions to the DTI and to assist the Government in meeting its Kyoto commitments. This is a voluntary initiative by industry.

3.4.9.4 Research

Research effort in the area of 'atmospheric emissions' was low. The majority of the research in this area involved environmental control technology and procedures, processes and techniques implemented to minimise atmospheric emissions. This was undertaken by industry and oil service companies.

3.4.9.5 Developments & Trends

In March 1999, the DTI sent out a consultation paper to industry detailing the proposed implementation of EC Directive 96/61 on Integrated Pollution Prevention and Control to offshore installations. The controls will be introduced as the Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 1999 under the 1998 Pollution Prevention and Control Bill. The regulations will become law by 30th October 1999 and apply to combustion plant with a single or combined rated thermal input exceeding 50 MW. They are directed at controlling emissions to air from power generation and promote the use of 'Best Available Techniques' to achieve emissions reduction. The DTI is proposing to integrate and streamline existing environmental controls into a single permitting system. This review and subsequent process of integration and improvement is predicted to take 3 to 4 years (Department of Trade and Industry, 1999d).

There are a number of indicators that regulation in this area will become tougher. The first is a conclusion from a survey conducted by the DETR was that individuals consider that atmospheric pollution will be the major environmental issue of the future. The second is that the Government is working on a new draft UK climate care programme. Finally, earlier this year, the Advisory Committee on Business and the Environment set out the following recommendations of action in a report to the Prime Minister (ACBE, 1998):

- implementation of a 'global warming gas emission reduction' national programme covering all sectors (including domestic and transport);
- promotion of new products and services to achieve energy efficiency;
- coverage of carbon consumption to promote future saving;
- establishment of voluntary targets for reduction;
- negotiation of legally-binding sectorial agreements, with appropriate incentives;
- promotion of the European Directive on Integrated Pollution Prevention and Control, as a preferred instrument to achieve energy savings (whilst maintaining option of carbon trading);
- introduction of a carbon tax;

- carbon trading between Kyoto signatories;
- development of combined heat and power and renewables;
- assessment of the potential of nuclear power;
- development of environmental control technology - research; and
- development of business strategy to consider the longer-term consequences of climate change.

3.4.10 Sustainable Development

Sustainable Development is founded on the notion that conservation and development are mutually dependent.

3.4.10.1 Definition

There are many definitions of sustainable development, however the widely accepted definition is:

"development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The World Commission on Environment and Development (WCED) published this definition in the Brundtland Report in 1987. The harmonisation of financial management with sustainable development has resulted in the emergence of the concept of the triple bottom line of sustainability: economic prosperity, social justice and environmental quality (Elkington, 1997). The UK first set out its commitment to the principles of sustainable development in its 1990 White Paper – '*This Common Inheritance*' (HM Government, 1990). In 1994 the Government published a guide to sustainable development called '*Sustainable Development: The UK Strategy*' (HM Government, 1994). This was updated in 1999 under '*A better quality of life: A strategy for sustainable development for the United Kingdom*' (HM Government, 1999).

3.4.10.2 Research

There has been limited research into 'sustainable development' and how it can be incorporated into or how it will affect the Oil and Gas Industry. BP, Philips Petroleum Company, Shell Exploration and Production, and Unocal have proactively incorporated the concept into their company policy on improving environmental performance. They have also begun reporting on the sustainability of their operations in their environmental reports. Operators are increasingly trying to understand what sustainable development requires of their businesses. Some are playing an active role in this determination. For example BP is a signatory to the International Chamber of Commerce Business Charter for Sustainable Development and a member of the Advisory Committee on Business and the Environment (ACBE).

3.4.10.3 Developments & Trends

Eco-efficiency is a business-like approach to sustainability. The term 'eco-efficiency' was launched in the 1992 Earth Summit book *'Changing Course'* as a management philosophy that aims at running a business more efficiently in both economic and ecological terms. In the 7th ACBE progress report it was concluded that UK businesses should take a positive view of sustainable development by focusing on eco-efficiency - in the World Business Council on Sustainable Development's useful phrase "getting more from less" (ACBE, 1997). Eco-efficiency may be defined as a measure of the relative amount of pollution or resource used required to produce a unit of produce or service. BP measures offshore eco-efficiency on the basis of exploration and production emissions and discharges as a % of production (British Petroleum Company, 1997b).

4 Holistic Environmental Assessment & Offshore Oil Field Exploration and Production

4.1. SUMMARY

According to UK Government surveys, concern for the environment is growing. Environmental regulation of the industry is becoming wider in its scope and tougher in its implementation. Various techniques are available to assess how the industry can drive down its environmental impact and comply with environmental regulation. Environmental Assessments (EA) required by European law do not cover the whole life cycle of the project that they are analysing. Life Cycle Analysis (LCA) was developed to assess the environmental loadings of a product, process or activity over its entire lifecycle. It was the first technique used in environmental analysis that adopted what was described as a holistic approach. It fails this approach by not assessing accidental emissions or environmental impacts other than those that are direct. Cost Benefit Analysis (CBA) offers the opportunity to value environmental effects and appraise a project on the basis of costs and benefits. Not all environmental effects can be valued and of those that can there is considerable uncertainty in their valuation and occurrence. CBA cannot satisfactorily measure the total environmental risk of a project. Consequently there is a need for a technique that overcomes the failures of project-level EA, LCA and CBA, and assesses total environmental risk. Many organisations such as, the British Medical Association, European Oilfield Speciality Chemicals Association, the Royal Ministry of Petroleum and Energy (Norway) and Shell Expro now recognise that a holistic approach is an integral part of assessing total risk. The Brent SPAR case study highlights the interdisciplinary nature required of any environmental analysis. Holistic Environmental Assessment is recommended as such an environmental analysis.

4.2. INTRODUCTION

This chapter reviews the need for a new holistic technique to assess total environmental risk from offshore oil and gas exploration and production. It explores the origin of the concept of holism and reviews current techniques that are used to assess environmental risk. Holistic Environmental Assessment is recommended by the author as a process of environmental analysis to assess total environmental risk. This chapter also highlights how environmental issues are increasingly being approached holistically and that this appears to be a reflection of an increased concern over environmental impacts and a fortification of the offshore environmental regulatory regime.

4.2.2. Corporate Accountability

When oil was first produced offshore in the UK in 1975, oil and produced water discharges were regulated by the Prevention of Oil Pollution Act, 1971, and statutory controls implemented by the Department of Energy. UK law did not require Environmental Assessment for field developments. Today, EA is a statutory requirement and environmental regulation of the industry has broadened and become tougher. This is characterised by the recent implementation of the Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations 1999, The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000 and the changes in decommissioning policy under the Petroleum Act 1998. It appears that environmental regulation will continue to get tougher as more EU environmental Directives are implemented (Moore, 1999). Industry is also being held increasingly accountable for its operations through 'soft law' concepts such as the 'precautionary principle', 'polluter pays' and 'producer responsibility'. Consequently, operators are publishing annual environmental reports to demonstrate to stakeholders their progress in improving environmental performance (Salter & Ford, 2000).

4.2.3. Corporate Responsibility

The industry is clearly therefore being closely controlled by legislation. However, the environmental performance of the UK offshore oil and gas industry in the 21st century is also being measured against a broader agenda based on corporate accountability and responsibility, and this appears to be becoming a core business issue. A 1999 advertisement by Shell stating its commitment to generate renewable energy for the public, confirms this:

> *"Ignoring alternative energy is no alternative. Keeping pace with the world's accelerating demand for energy and supplying power to remote areas require Shell to pursue renewable resources like solar, biomass and wind energy. We established Shell International Renewables with US$500 million commitment to develop these new opportunities commercially. One of our goals is to make solar energy cheaper, more efficient and more accessible both for businesses and homes. It's part of our commitment to sustainable development, balancing economic progress, with environmental care and social responsibility. So with real goals and investment, energy from the sun can be more than just a daydream".*
>
> (Shell International, 1999)

The change in the attitudes of the large oil and gas companies is demonstrated by their diversification into alternative sources of energy. Energy historians will remember 1997 as the year in which two of the world's largest oil companies took a major step into the development of alternative sources of energy by announcing that they were making major investments in solar and wind energy. In this year BPAmoco and Shell committed respectively US $1 billion and US $500 million to the development of wind, solar and other renewable energy resources. This highlighted the fact that the companies take the threat of global warming seriously and are metamorphosing into energy companies (Worldwatch Institute, 1998).

They will also remember the late 1990s as a period where Greenpeace and Friends of the Earth campaigned against the exploitation and burning of fossil fuels, particularly against oil exploration in the Atlantic, Northwest of Scotland and BP's Northstar and Liberty projects in the Beaufort Sea. Both groups were concerned that the agreements in the Kyoto Protocol are not being implemented effectively and that the science behind climate change was being brushed aside for short-term economic gain. The groups were attributing large-scale natural disasters to the activities of the industry:

"We in Bangladesh are experiencing the impacts of climate change first hand. Last year's floods brought death and devastation to our country and people. We hold companies like Exxon and Mobil responsible."

(FOE, 1999)

4.3. HOLISTIC ENVIRONMENTAL ASSESSMENT

4.3.1. Definition

Holistic environmental assessment (HEA) is a goal orientated process that utilises knowledge from all available sources and disciplines. It attempts to give an accurate account of the total environmental risk to society arising from all phases of a process designed for the manufacturing of a product and/or provision of service. It aims to ensure that, in a competitive global market, strategies to reduce pollution in a particular phase of a process do not lead to greater pollution in another.

HEA focuses on the qualification, quantification and prioritisation of environmental impacts from activities in each phase of a chosen process. These impacts are represented as pathways and detail direct, secondary, indirect and cumulative environmental impacts. They are analysed in relation to other activities in a chosen geographical area to assess total environmental risk. Identification of impacts includes those that are both actual and perceived by society as warranting concern. Consequently, such pathways are chains of causality, initiated by a specific activity, that span environmental science, engineering, economics and law.

Conceptually, HEA, like nature, has few boundaries and in practice, simplifications will have to be introduced to ensure that an appropriate level of detail is assessed. HEA may be used either as a planning or comparative assessment tool. Consequently it will be useful to governments, industry and non-governmental organisations in their efforts to perform environmental analyses at a strategic level. Figure 4.1. details the framework of an HEA to calculate total environmental risk from a process.

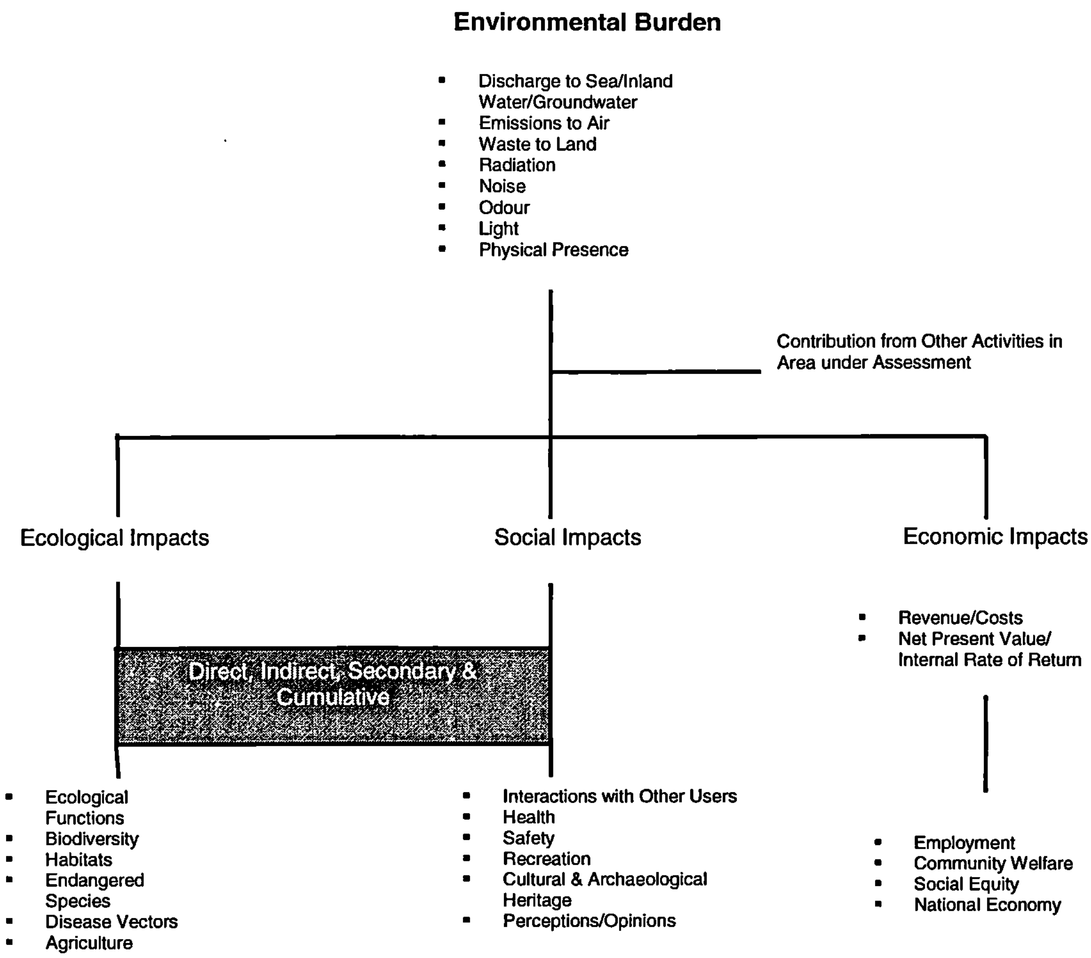


Figure 4.1. Holistic Environmental Assessment Framework

4.3.2. Environmental Impact Assessment

Under ISO 14001, an environmental impact is defined as 'any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activities, products or services' (Institute of Environmental Management, 1996). Environmental impacts take a variety of forms. An impact may be sudden and acute but it may also occur indirectly, such as when pollutants may act together to form effects greater than predicted by summing the individual impacts. The gradual build-up of a pollutant may cause a wider impact, experienced over a long period of time, perhaps through many human generations.

HEA is an appraisal system that can define the link between environmental burden and the cost and/or benefit of the activity to industry and society. Benefits to society can be represented by damage to the environment avoided (i.e. maintaining environmental quality) through the implementation of environmental technologies and environmental enhancement programmes. To achieve such benefit the industry will incur cost. These costs and benefits will either be directly quantifiable e.g the cost of environmental technology, or not, e.g. the benefit achieved by reducing the damage caused by secondary pollutants from SO_2 and NO_x.

4.3.3. Goal Definition & Scoping

A Holistic Environmental Assessment will:

1. identify the primary phases of a proposed process or currently employed process for the manufacturing of a product and/or provision of a service
2. identify any phases escaping environmental regulation
3. allow the identification of best available techniques to minimise the environmental impact of a proposed process
4. assess the current level of environmental burden for the geographical area under development, and analyse the environmental risks in the wider area
5. qualify, quantify and prioritise the environmental aspects
6. calculate the total environmental risk to society posed by various environmental risk mitigation systems designed for the process
7. identify an eco-efficient and cost-effective environmental risk mitigation system.

4.3.4. Application

Conceptually HEA has few boundaries and in practice, to keep analysis at a manageable level, simplifications will have to be introduced to ensure that an appropriate level of detail is assessed. Thus, HEA may be used either as a planning or comparative assessment tool. Consequently it will be useful to governments, industry and non-governmental organisations in their efforts to perform environmental analyses at a strategic level.

4.4. HISTORY OF HOLISTIC ENVIRONMENTAL ASSESSMENT THEORY

4.4.1 Concept

The concept of considering the environment as a whole is not new. In his book, Holism and Evolution, Jan Christian Smuts (South African statesman-scholar) stated that:

"Holism leads you to the concept of wholes. Wholes are arrangements. Science has to come round to the view, that the world consists of patterns, and I construe that the world consists of wholes".

In the 1920s this concept challenged the perspective of science that considered that ecosystems existed in isolation (Savory, 1988). The Gaia hypothesis developed by James Lovelock in 1979 has also proven to be controversial. It considers the earth as a single complex organism which is both self-regulating and self-organising. It is suggested that biotic elements attempt to moderate their local environment to bring about an optimal chemical and physical environment for all life forms in which there is sufficient oxygen for animals and sufficient carbon dioxide for plants. It is also suggested that the 'Gaia' mechanism moderates atmospheric and oceanic temperatures by a controlled 'Greenhouse Effect' as well as regulating the major biochemical cycles essential for life, that is water, oxygen, soil and rock (Jones et al., 1990). Thus, there is theoretical evidence that the environment is not merely a series of separate and distinct ecosystems with no, or even limited, interaction, but rather a complete system where interactions are complex, numerous and at times unpredictable. This theory is being proved with our improved understanding of the fate of pollutants and the extent of their effects. The offshore industry on the UKCS must be considered very much a part of nature. That is not to say that whatever industry may do is natural and therefore 'good' nor, is it all 'bad'. The intellectual challenge that we appear to face is to identify the 'middle ground', and ensure environmental quality. It is impractical to try and conserve biological diversity and ecological continuity by excluding man and his works (Callicott, 1992). As environmental issues broaden, man's relationship with them is becoming increasingly seen in terms of liability for polluters, and risk for potential sufferers of environmental degradation (pollutees).

4.4.2 *Origins*

Holistic Environmental Assessment was born out of an analysis undertaken by an ecologist to help halt 'desertification' in Zimbabwe and the United States. Desertification is a form of environmental damage that is commonplace in these countries. The ecologist, Allan Savory working as a land ranger in Zimbabwe observed that, when using conventional farming techniques, of spatially distributing animals to avoid overgrazing, there was a deterioration in grassland quality, resulting in the death of large numbers of cattle. Even with fewer cattle the land continued to deteriorate. Records at the time of study show that the area received one of the best rainy seasons both in terms of volume and distribution. He observed that this degradation did not occur in Europe, even in areas receiving between 15-20 inches of rain per year. Mitigation measures such as planting grass (at considerable expense) and clearing bush did not alleviate the deterioration.

Following a detailed analysis of food chain linkages, it was discovered that, by comparison with areas where people herded domestic stock, where stock was fenced in, and where there were no large 'grazers' at all, the environment where 'grazers' were herded naturally was sustained for future generations. For in the wild, when a herd finishes feeding and continues its migration, or when threatened by predators, it gathers together, kicks up dust and tramples down plants. In addition, the subsequent trotting and galloping chips and breaks up the surface layer of the soil. This can be likened to the action of a garden hoe. Steep edges of any gullies are also beaten down. Where people herded domesticated cattle, it was recorded that when feeding, animals tread carefully between coarse plants and space themselves out thereby preventing any break-up of the soil's surface layer. A soil surface that was capped from compaction, and protected by coarse plants when the rainy season came would limit the effectiveness of precipitation. The result is that the 'reservoir' of water retained in the soil is limited and shallower, and the soil is poorly aerated. The soil is unable to effectively sustain the range of species that would otherwise occur naturally. This situation would occur wherever the natural herding of animals was absent. Thus, the hooves of herding natural game were discovered to be vital to the health of the land. It was concluded that the effectiveness of the ecosystem was related to the integration of the processes associated with the water cycle, various minerals cycles (which include atmospheric processes), biological succession and energy flows. This knowledge led to improved land management with economic benefits (Savory, 1988).

4.5. DEVELOPMENTS IN THE DIRECTION OF A HOLISTIC APPROACH TO ENVIRONMENTAL ASSESSMENT

4.5.1 International

4.5.1.1 Draft International Standard Order 14040 & Associated Standards on Life Cycle Analysis

Life-cycle analysis (LCA) is described as a holistic, cradle to grave technique of analysing the environmental loadings of a product, process or activity over its entire lifecycle. To make meaningful comparisons between the environmental loadings of different materials or products, a common reference unit is decided upon (Institute of Environmental Management, 1998). Early LCA studies were carried out in the US in the late sixties and early seventies for plastic packaging, diapers and beverage containers. It wasn't until the mid-1980s that LCA was conducted in Europe. Following the Brundtland report, Our Common Future, and acceptance of Sustainable Development by governments, the application and interest in LCA has grown. The growth in the application of LCA in a wide range of subject areas has increased the need for standardisation. In response to a need for a harmonised approach to LCA, the International Organisation for Standardisation published ISO 14040 Environmental management – Life cycle assessment – Principles and framework, and the associated draft standards ISO 14041, -42, -43 & -49 (VITO, 1995). Although LCA is meant to be holistic, there are shortcomings:

- The data required by a LCA are mostly related to mass and energy balances during normal operations and, accidental emissions are not considered
- LCA is linked to direct impacts and does not quantify indirect, secondary and cumulative impacts of activities over a whole chain of activities

- LCA is not interdisciplinary and does not simultaneously assess the impact of other factors such as engineering, legislation, socio-economics and politics on a product, process or activity.

4.5.1.2 Cost Benefit Analysis

Cost Benefit Analysis (CBA) offers a rigorous way of setting out the effects of a proposed project. It attributes a social value to everything affected by a project, and sums the costs and the benefits. A project is worth considering when its benefits exceed its costs. While a project whose benefits are less than its costs is not. Although the use of CBA is universal there is no formal standard. This is due to the variety of methods that may be used to assess costs and benefits. CBA would be useful in environmental management, as there is no other mechanism available that informs us whether a project is desirable or not. Environmental Assessment informs us of the relative impacts of an action, but does not provide us with a clear framework to identify whether the project is desirable or not (Hanley, 1995). For these reasons CBA theory is integral to project appraisal and environmental valuation, however it has a number of weaknesses that need to be addressed:

- there are environmental effects that are not scientifically fully understood and consequently cannot be satisfactorily valued in monetary terms and are thus, set aside;
- there is considerable uncertainty in the occurrence of environmental effects, their extent and the estimates of the value of these effects, which is not fully addressed by CBA. Consequently, CBA cannot measure the total environmental risk posed by a project;
- by putting a monetary value on the internal and external costs and benefits, and representing this as a final value, there is a risk that CBA takes the decision away from those who should be taking it. This could arise where a third party will be affected significantly by a specific environmental impact, and yet this is hidden in the final sum of cost and benefit.

4.5.2 European Developments

4.5.2.1 Strategic Environmental Assessment

In 1996 the European Commission adopted a Proposal for a Directive on Environmental Assessment of plans and programmes for development consent procedures, also known as the Strategic Environmental Assessment (SEA) Directive. In February 1999 this proposal was amended after the European Parliament had its first reading. This amended text formed the basis for negotiations at Council level with the 15 Member States in the course of 1999. Finally in December 1999 the Environment Ministers reached a political agreement on a common text for the future Directive (the common position). The common position was formally adopted on 30/03/2000. The European Parliament as co-legislator will now get a second opportunity to comment and propose amendments in a second reading. The final Directive should be adopted by the end of the year 2000. Afterwards Member States will have three years for integrating the new instrument into their national systems (Directorate-General XI, 2000). SEA will take a wider approach to project level environmental assessment as it will be used to assess the environmental impacts of decisions made at a strategic level. It will also allow the public to give their opinion on such decisions (Partidário, 1996). This has been defined as the:

"formalised, systematic and comprehensive process of evaluating the environmental impacts of a policy, plan or programme and its alternatives, including the preparation of a written report on the findings of evaluation, using the findings of that evaluation, and using the findings in publicly accountable decision making."

(Therivel, 1992)

4.5.2.2 Norwegian Legislation

Before 1997, Environmental Impact Statements prepared for new developments offshore Norway received criticism from environmental and fishery organisations for insufficiently evaluating the combined environmental effects caused by oil and gas activities in the area (Strøm, 1998). Such criticism demonstrates how easily it is for a regulator to become accountable for the activities of industry. Issues raised from this criticism included:

- the increasing concern about the environmental impacts on society
- the increasing awareness of the need to evaluate the impacts of all emissions and discharges, and occupation of areas within a region
- failure to include other factors which influence the total environmental risk to an area
- the need to have a policy for the area which is in accordance with its specific environmental sensitivity.

This led to a change in the Norwegian Environmental Impact Assessment (EIA) based system and the development of Regional Environmental Impact Assessment (REIA). The Royal Ministry of Petroleum and Energy (MPE) established the legal basis for REIA in July 1997. REIA focuses on regional impacts. The main issues include:

- description of the overall petroleum activity in an area
- total emissions to air and sea and accidental risks from activities
- environmental resources and sensitivity of the area
- global and regional impacts on the environment and natural resources
- socio-economic impacts
- environmental technology available to reduce the impacts and potential reductions which may be achieved
- regional environmental monitoring programmes.

Once a REIA has been prepared for a given area, companies, proposing to operate in this area, can prepare a less comprehensive EIA. Whilst REIA is not legally binding for any of the operators in an area, the preparation of Environmental Statements is (MPE, 1999). The idea behind the regional approach is that, by using one contractor to survey an area, operators co-operate together to ensure consistent analytical information (Bryne, 1999).

The REIA is submitted together with a field specific EIA to constitute the total environmental assessment for that field (Furuholt E & Kinn S J, 1998). The benefits of such a system are that it:

- provides common and key information
- includes other activities
- avoids conflicting and doubling of work
- increased understanding of environmental processes
- ensures that the total activity in the area does not impose unacceptable impacts
- provides an opportunity for a less prescriptive approach
- faster preparation and processing of environmental statements
- improved basis for monitoring programmes (Strøm, 1998).

The REIA system provides a better basis than EIA for evaluating total environmental and socio-economic effects in an area (Furuholt E & Kinn S J, 1998). By focusing on evaluating such effects, i.e. modelling cause and effects, the prediction of regional impacts from emissions to air and water is enhanced and made more plausible.

4.5.3 Developments in the United Kingdom

4.5.3.1 Environmental Legislation

Chapter 3 identified that one of the key indicators of the range of environmental issues being addressed by the UK Government is the increase in environmental legislation. This section summarises the legal developments that are forcing analysts to take a holistic perspective to environmental assessment. At the beginning of 1999, there were over 300 environmental EU Directives and according to officials from the Department of the Environment, Transport and the Regions officials, the number of statutes and statutory instruments runs into the thousands (Moore, 1999). Figure 4.2. details the increase in environmental EU Directives since 1967.

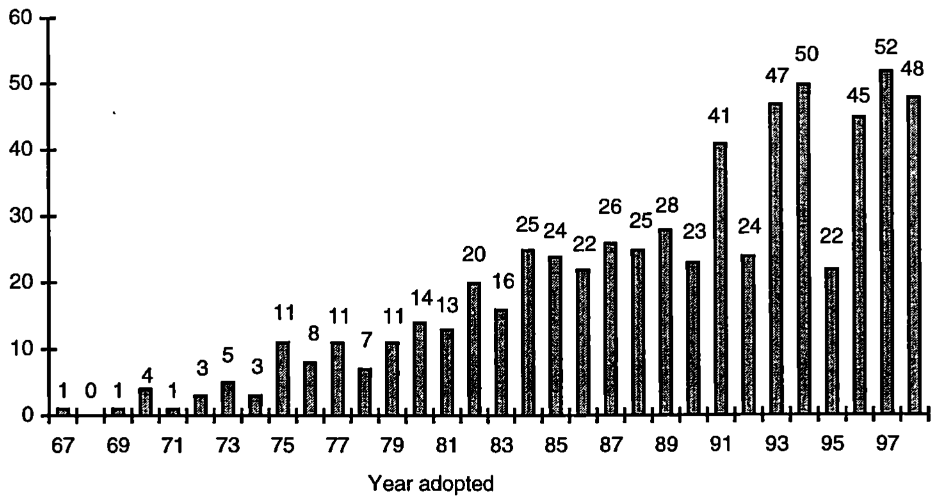


Figure 4.2. EC Environmental Legislation Adopted by the UK Each Year
Source: The Manual of Environmental Policy: The EU and Britain; Edited by Nigel Haigh, 1992 (updated every 6 months)

In the last five years there have been a number of developments in the regulatory regime offshore. UK law requires that an Environmental Statement be prepared for all major offshore field developments. In April 1998, the Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations, were introduced. Commonly termed the 'Offshore EA Regulations', they implemented the EEC Environmental Assessment Directive 85/337/EEC. These regulations were amended in March 1999 to implement the amended EC Environmental Assessment Directive (97/11/EC). The environmental regulation of the UK offshore oil and gas industry is becoming increasingly stringent and covers emissions to all media, air, water and land. Other developments in the legislation include:

- The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000 (draft) - control emissions to air from power generation and promote the use of 'Best Available Techniques' to achieve emissions reduction. They apply to combustion plant with a single or combined rated thermal input exceeding 50 MW
- The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations, 1998 – requiring an oil spill contingency plan be made

available to the DTI and the Marine and Coastguard Agency (MCA) for approval two months before drilling begins

- The Harmonised Offshore Chemical Notification Scheme (HOCNF) standardises the testing and reporting of all chemicals used by the oil and gas industry in the entire North East Atlantic area. It was introduced in 1996 by the DTI. This is in preparation for when it will become statutory under the Harmonised Mandatory Control System.
- OSPAR Decision 98/3 - prohibits the dumping, whole or partial abandonment of disused installations in the North Atlantic. It was agreed by contracting parties to the OSPAR Convention at the first Ministerial Meeting of the Oslo and Paris Commission.

Onshore regulation of waste disposal is more established when compared to the equivalent regime offshore. Onshore disposal of waste is controlled by a variety of environmental laws. This includes: Environmental Protection Act 1990; Environment Act 1995; Waste Management Licensing (Amendment) Regulations 1996, and the Special Waste Regulations (1996). This legislation imposes a 'Duty of Care' mechanism on waste producers to take all reasonable steps to ensure that waste is handled lawfully and safely. On land waste must be disposed of by a licensed operator and in a licensed facility. Under the law, the awarding of waste management licences by the Environment Agency in England and Wales or the Scottish Environmental Protection Agency in Scotland are dependent upon: the type of waste, the proposed treatment, keeping or disposing of controlled waste; and, the technical competence of the proposed licensee.

4.5.3.2 Legal Targets for Discharges to the Sea

At the first annual Ministerial Meeting of the OSPAR Commission held in 1998, it was agreed that a cessation of discharges, emissions and losses of hazardous substances from offshore oil and gas field exploration and production would be achieved by the year 2020 (OSPAR, 1998a). This decision has influenced the development of the concept of a 'zero discharge' offshore industry. Although there are various interpretations of this phrase, it is generally used by the offshore industry to mean that no oily cuttings are discharged to the sea (Thomas, 1999).

A new protective zone around the UK coasts, in which oil discharge from ships will be prohibited, came into force on 1st August 1999. In a meeting in April, 1998 the Marine Environment Protection Committee of the International Maritime Organisation (IMO) designated the seas around the UK and North West European coastlines as a MARPOL Annex 1 special area (Department of Environment, Transport and the Regions, 1998). Under Regulation 10, any discharge into the sea of oil is banned from shipping except vessel drainage water, which must not exceed 15-ppm oil in water content. The MARPOL Convention defines a ship as 'floating craft, and fixed or floating platforms'. Consequently under Regulation 21, facility drainage discharge from oil and gas field developments must also achieve the same discharge criterion (IMO, 1997). Since the 6th July 1998, this discharge requirement for platform drainage has been in force under an amendment to the Merchant Shipping (Prevention of Oil Pollution) Regulations 1997. The MARPOL Convention does not control other sources of oil-based discharges from offshore oil and gas exploration and production.

4.5.3.3 Legal Targets for Discharges to the Atmosphere

At the Kyoto Conference (1-11/12/97), the EU agreed to reduce gaseous emissions, based on a basket of six greenhouse gases, by 8% of 1990 levels by the period 2008 to 2012. The six gases include Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbon (HFC) & Perfluorocarbon (PFC), Sulphur hexafluoride (SF_6). The UK's legally binding target will be greater than 8% and will be achieved as part of a staged programme aimed at achieving a 20% CO_2 reduction by 2010. This would be an overall reduction of 36 million tonnes of carbon (Advisory Committee on Business and the Environment, 1998). The government's commitment to the Kyoto Protocol will, almost certainly, result in a toughening of the DTI's regulation of hydrocarbon emissions into the atmosphere.

4.5.3.4 UK Case Law

In November 1999, Greenpeace challenged the Secretary of State for Trade Industry for failing to administer the Habitats Directive into the 19th Offshore Oil and Gas Licensing Round and therefore apply it outside UK territorial waters. The case concluded that UK regulations had failed to lawfully implement the Directive. The London High Court ordered the UK government to apply the EU Habitats Directive throughout its 200-mile exclusive economic zone (Foreign & Commonwealth Office, 1997) before the DTI grants any new offshore oil or gas exploration licences. Greenpeace hailed the outcome as a "landmark ruling that will set a precedent throughout Europe." The judgement is the first on this point by an EU national court. It represents a significant extension of the Directive's reach, since no countries have designated conservation sites beyond 12-mile national territorial limits. The case was heard before Justice Maurice Kay, who was prepared to accept that there was sufficient evidence that oil exploration was 'at least likely' to have 'an adverse effect' on deep water corals and whales and dolphins. In particular, it means the Department of Trade and Industry will have to take additional steps to ensure that cold-water coral are protected during hydrocarbon exploration. It also ensures that whales and dolphins are not disturbed during these activities (Environmental Data Services, 1999). A key point in this judgement is the use of the precautionary principle, which may be significant in terms of future environmental protection (Lee, 1999).

4.5.4 UK Public Opinion

The events surrounding the Brent Spar (detailed below) highlight that societal opinion can strongly influence the behaviour of offshore oil and gas industry. Concern for the environment not only exists, but it is becoming stronger. Moreover, the breadth of issues that individuals are concerned about is widening. The following Tables detail results from UK Government surveys that assess the concern that people have for the environment.

Levels of Concern (%)	*All 1993*	*All 1996/7*	*Sex Male*	*Female*	*Age 18-24*	*25-44*	*45-64*	*Over 64*
Very concerned	30	29	30	28	20	26	35	35
Fairly concerned*	56	59	59	60	66	63	55	48
Not very concerned	11	9	10	9	8	9	8	13
Not all concerned	2	2	1	2	3	1	1	3
Don't know	1	1	-	1	3	-	-	-
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 4.1. Public Concern about the Environment in General (England & Wales)
Source: Department of the Environment, Transport and the Regions (1998a)
* "Quite concerned" in the 1993 Survey

It is clear from the above table that concern for environmental quality exists. People throughout the UK appear to be concerned that the pollution and environmental damage affect them in their day-to-day life. Data from a 1998 MORI environmental poll in Table 4.2. suggest that this concern has been unwavering and well-founded.

(Base: c. 1000)	*1992* %	*1993* %	*1995* %	*1996* %	*1997* %	*Change 97-96* ±%
Agree	70	73	73	69	73	+4
Disagree	14	14	14	18	16	-2

Table 4.2. MORI Survey
Source: MORI 1998 Poll
"Pollution and environmental damage are things that affect me in my day-to-day life"

The Department of the Environment, Transport and the Regions has obtained 'concern' data for the years 1986, 1989, 1993, and 1996/7 (DETR, 1998a). In part of the study individuals are asked to express how worried they were about 32 environmental issues.

Environmental Issues	*1986*	*1989*	*1993*	*1996/7*
Chemicals put into rivers and the sea	54	64	63	65
Sewage on beaches /bathing waters	(37)	59	56	61
Radioactive waste	62	58	60	60
Toxic waste: disposal and import	..	..	63	60
Oil spills at sea and oil on beaches	(27)	53	52	56
Traffic exhaust fumes and urban smog	23	33	40	48
Ozone layer depletion	..	56	41	46
Use of insecticides/pesticides	39	46	36	46
Loss of plants and animals in the UK	(38)	(45)	43	45
Loss of plants and animals abroad	..	..	38	44
Tropical rainforest destruction	..	44	45	44
Traffic congestion	..	..	35	42
Fumes and smoke from factories	26	34	35	41
Loss of trees and hedgerows	(17)	34	36	40
Drinking water quality	..	41	38	39
Losing greenbelt land	26	27	35	38
Global warming	..	44	35	35
Fouling by dogs	30	29	29	34
Effects of livestock methods	..	..	..	33
Acid rain	35	40	31	31
Litter and rubbish	30	33	29	30
Over-fishing of the seas	..	..	..	30
Smoking in public places	..	..	..	28
Difficulty in travelling in means other than car	..	..	..	26
Decay of inner cities	(27)	22	26	23
Using up UK's natural resources	..	..	27	23
Need for greater energy conservation	..	..	21	22
Household waste disposal	..	..	22	22
Public water supply restrictions	..	..	..	22
Not enough recycling	..	..	19	18
Vacant and derelict land /buildings	..	16	19	18
Noise	10	13	16	15

Table 4.3. Percentage "very worried"* about each environmental issue: 1986, 1989, 1993, and 1996/7 (England & Wales)

Source: Department of the Environment, Transport and the Regions, Digest of Environmental Statistics No. 20, 1998. In 1996/7 respondents were asked to express their level of concern about 32 environmental issues. This table shows the percentages that were very worried

() Issues in this earlier survey are not directly comparable with 1996/7

.. Issue not included in this earlier survey

Individuals were primarily concerned about pollution of inland and offshore waters. The Scottish Office reflected this concern in research in 1991, and undertook the study, with similar issues used by the Department of Environment's 1989 survey (Scottish Office, 1991). Of the 22 topics covered in the Scottish survey, the pollution of the rivers, lochs and sea and raw sewage put into the sea were the two issues that most concerned people.

Environmental Issue	*Score*	*Environmental Issue*	*Score*
Pollution of rivers, lochs and seas	64	Protection of Wildlife	32
Raw sewage put into the sea	62	Generation of Electricity by Nuclear Power	31
Quality of drinking water	57	Using up non-renewable resources	27
Nuclear Waste	56	Over fishing	23
Damage to the ozone layer	56	Forestry	19
Road traffic	51	Farming methods	19
Fumes and smoke from factories	50	Protection of areas of conservation interest	16
Global warming by greenhouse effect	47	Derelict land in towns and cities	13
Acid rain	41	New development in the countryside	9
Pesticides, fertilisers and chemical sprays	41	Lack of access to parks	6
Waste disposal	36	Fish farming	3

Table 4.4. Public Attitudes to the Environment in Scotland
Source: Scottish Office (1991)
22 selected environmental issues were investigated in terms of how serious the issue was, how personally affected people were, and how worried they were about it. As the rankings were closely correlated, these were combined in a single concern index. A low score reflected high concern. If an issue had been ranked first on all three measures its score would be 3 and if an issue had been ranked last on all three measures its score would be 66. Subtracting them from 69 to give a high score for high concern reversed the scores.

Pollution of the atmosphere is an environmental issue that individuals are concerned about. Transboundary atmospheric pollution, such as global warming and acid rain, concerned individuals in England and Wales less by comparison with localised pollution from road traffic and factories. The exception to this was ozone layer depletion. This was of highest concern in this area. In the Scottish survey too, localised pollution from road traffic and factories concerned individuals more than global warming. The health effects in the UK from ozone layer depletion and localised air pollution, skin cancer and asthma respectively, are clearly documented on for the public by UK Government Departments (Department of Health, 2000; Department of the Environment, Transport and the Regions, 1999). By comparison, to discover those that may arise from enhanced global warming requires a more detailed search of scientific journals. When asked about future environmental concerns, individuals placed atmospheric pollution ahead of water pollution (see Table 4.5.).

Environmental issues/trends	*1993*	*1996/7*
Traffic (congestion, fumes and noise)	36	37
Global warming/climate change	27	32
Level of air pollution	29	30
Level of pollution in lakes, rivers and sea	24	23
Depletion of ozone layer	20	22
Loss of tropical rainforests	15	15
Population growth	12	14
Using up the world's natural resources	11	12
Toxic waste	13	10
Loss of countryside through urban development	10	10
Radioactive waste	15	10
Loss of rare species	8	9
Disposal of household waste	8	6
Too many roads/motorways	4	6
Acid rain	5	4
Sea level rise	..	4
Decay in inner cities	5	3
Destruction of natural and/or heritage sites by tourism	..	2
Genetically modified organisms	..	1

Table 4.5. Future Environmental Concerns (England & Wales)
Source: Department of the Environment, Transport and the Regions, Digest of Environmental Statistics, (1998)
Respondents were asked what environmental issues or trends would cause them the most concern in about 20 years time. Respondents were not prompted with suggestions nor allowed to see any picture prompt cards.
.. Issues were not mentioned in the 1993 survey

Study of these tables suggests that the environmental issues that concern people the most are those relating to the health and welfare of an individual. The 1996/7 England and

Wales survey identified that the issue most important to people in their lives was 'having good health'. When asked who should clean up pollution, 68% of respondents recommended the 'polluter pays' principle, despite the fact that it may mean a higher price for goods and services. The 1996/7 survey also analysed individuals' understanding of environmental impact. Upon presentation of a list of potential global warming effects and questioning about these effects, there was a high agreement that there would be changes in local weather and temperature. However, there appeared to be significant misunderstanding when asked about causes. The more issues that the public become concerned about and that require more in-depth consideration, then the more holistic environmental assessments will have to become.

4.5.5 Institutional Opinion

4.5.5.1 European Oilfield Speciality Chemicals Association

At the 1998 Society of Petroleum Engineers International Conference on Health Safety and the Environment in Caracas, the European Oilfield Speciality Chemicals Association (EOSCA) presented a paper that discussed the changing regulation surrounding chemical use and discharge to the North Sea from oil and gas exploration and production. It examined the current situation of increasing environmental controls and regulations, the appropriateness of certain test protocols, the over-reliance on hazard assessment, and the potential dangers that this could pose to the industry. Following an environmental impact analysis, two products were identified as posing the same level of risk to the environment under the UK Offshore Chemical Notification Scheme. However, when they were submitted to the UK authorities for approval, the authorities were unable to classify one of them under this scheme. In agreement with the regulators, additional tests were performed and still the authorities felt uneasy classifying the product. Consequently, EOSCA considers that assessing the environmental impact of chemical discharge and the risk of its occurrence needs to be pursued holistically to avoid such anomalies and ensure transparency (Craddock & Moorfield, 1998).

4.5.5.2 British Medical Association

In 1998 the British Medical Association (BMA) published a report which examined the practice of environmental impact assessment. It identified that the most significant failing of EIA is that it focuses primarily on the physical, chemical and biological environment, and that there should be a facility to adopt a holistic approach that includes human health effects.

As discussed above, the public is primarily concerned with those issues that could adversely affect their health. The BMA's report highlights an urgent need for methodologies to be developed that recognise, characterise, estimate and ameliorate adverse environmental health impacts. The association also identified the need for more epidemiological surveillance, both of occupationally exposed groups and of the general population (BMA, 1998). A further recommendation was that there should be more co-operation between the Department of the Environment, Transport and the Regions, and the Department of Health to ensure that the draft EC Directive on Strategic Environmental Assessment includes a provision for assessing impacts on human health.

4.5.6 Case Studies

4.5.6.1 The Brent SPAR

The Brent SPAR case study highlights how individuals and their perceptions can widen the scope of an environmental analysis. This was demonstrated by the events which followed the announcement of the decision by Shell Expro in March 1995 (with

Government approval) to dispose of the Brent SPAR in 200 m of water 240 km off Northwest Britain. A synopsis of these events is detailed in Table 4.6.

	Events
September 1991	Brent SPAR ceases operating
October 1991+	Decommissioning studies and consultations begin
October 1994	BPEO and impact hypothesis submitted to UK DTI – deep water disposal endorsed by Aberdeen University as BPEO
February 1995	UK Government approves deepwater disposal and notifies other signatories of the OSLO Convention. No objections are raised by signatories.
April 1995	Greenpeace activists occupy the Spar
May 1995	UK grants disposal licence for deep-sea disposal. Scientists state support for disposal as a balanced decision fuelling a subsequent debate. German Ministry of the Environment protest against BPEO.
June 1995	Several countries at the 4th North Sea Conference request that oil installations be disposed of on land. 200 Shell service stations are threatened by protesters in Germany – 50 are damaged (2 fire bombed and one raked with bullets). Following growing opposition in Europe against deep-sea disposal and safety threats, Shell announces that it will seek a licence for land-based disposal and apologises to UK Prime Minister for any embarrassment caused by the decision. It continues to maintain its decision that deep-sea disposal is the BPEO.
July 1995	Norwegian government grants permit to moor the SPAR in Erfjord pending a decision on its future. Shell commissions Det Norske Veritas (DNV) to conduct an independent audit of the installation's inventory. UK government insists that any alternative to the deep-sea disposal must match or reduce the risks to health, safety and the environment.
September 1995	Greenpeace apologises to Shell UK for its inaccurate claims about the Brent SPAR inventory. Greenpeace UK and Shell Expro meet to discuss BPEO. UK Scientists re-iterate their support for rational, science-based decisions at the British Association for the Advancement of Science.
October 1995	The Natural Environment Research Council (NERC) forms a Scientific Group on Decommissioning Offshore Structures (SGDOS) and begins an assessment of the technical and scientific considerations raised by the disposal of the Brent SPAR
December 1995	The global London Convention rejects the Oslo and Paris Commission's call for a moratorium on deep-water disposal of offshore installations. The 72 members of the London Convention agree to establish a Scientific Group of Experts to examine the full range of decommissioning issues
March 1996	A House of Lords Science & Technology Committee inquiry into decommissioning finds no overriding grounds for excluding deep-water disposal and suggests wider consultation in the future
May 1996	A report by NERC's SGDOS concludes that the environmental impact of deep-sea disposal of the SPAR would be very small
July 1996	Shell Expro tender bid for a BPEO from leading contractors and consortia, and introduce plans for a 'Dialogue Process'
August1996	Shell Expro receives 30 outline proposals and cuts this to 11 in January 1997
November 1996	First seminar in Brent SPAR dialogue process, others are held in 1997
January 1997	6 contractors and consortia are asked to develop the 11 proposals in detail
February 1997	DNV are commissioned to review the 11 short-listed proposals
June 1997	Shell Expro receives 9 detailed bids, these are represented on CD-ROM and video to aid the Dialogue Process. DNV reveal their findings of their study.
November 1997 - January 1998	Shell Expro carries out its final chosen BPEO evaluation and announce their choice as a 'on-off' reuse as a Norwegian Ro/Ro ferry quay. The Decommissioning plan is submitted to the UK Government
August 1998	UK announces its approval of the BPEO
November 1998	Decommissioning commences
July 1999	Final ring sections are placed in position at Mekjarvik using heavy crane vessel Thialf

Table 4.6. Brent SPAR Calendar of Events
Source: Shell Expro (1999)

There are a number of important factors to consider in the case of the Brent SPAR. When the decommissioning of the Brent SPAR was being considered, the Petroleum Act 1987 required that an Abandonment Programme was prepared and submitted for approval to the Department of Trade and Industry (DTI) for each installation on the United Kingdom Continental Shelf (UKCS). Shell Expro complied with these requirements and received approval for their proposed programme. They also adopted the international and UK practice of reviewing and identifying the Best Practicable Environmental Option (BPEO) for disposing of the SPAR. In this case, the BPEO analysis was required because at least one of the options involved the disposal of 'waste at sea'. The analysis began in 1991. Thus it can be asserted that Shell painstakingly complied with all regulatory standards and requirements (Side, 1997). Deep-sea disposal was not only considered the Best Practicable Environmental Option, but also the safest and cheapest (at $18.5 million dollars compared to $72.2 million for disposal on land).

When the mode of abandonment was announced, Greenpeace began a campaign against it by occupying the SPAR. There was no public reaction to Greenpeace's occupation in the UK. Reaction developed when, in Germany, the protestors blockaded, petrol bombed and boycotted Shell petrol stations (Shell UK Ltd, 1998). The Greenpeace campaign subsequently generated further reaction after findings from the June 1995 International North Sea Conference identified that the sea was suffering from significant environmental degradation. Even though the SPAR was to be disposed of west of Shetland, stakeholder concern was significant enough for the company to reassess the disposal option. After extensive re-evaluation by Shell Expro, the SPAR is being re-used as a new quay extension to provide role-on/roll-off ferry facilities at Mekjarvik, near Stavanger, Norway. The final disposal option costs to Shell are estimated to be between $71-76 million (*pers. comm.* Shell Expro, 1998).

The Brent SPAR controversy highlighted the need for a change in the industry's approach to decommissioning. European governments pressed for a change in decommissioning policy for offshore installations. Consequently, the UK Government in 1998 agreed to the OSPAR Decision 98/3 at the Ministerial Meeting of the OSPAR Commission, which prohibits the dumping of platforms weighing under 10,000 tonnes at sea. Reuse, recycling or final disposal on land is encouraged. The sequence of events identified that public opinion was not considered in the evaluation process for the BPEO (Side, 1997). Consequently, the UK upstream industry increasingly considers people's expectations and perceptions in environmental evaluation. This is evident in BP's approach to assessing significant impacts for the Schiehallion Field Development where *perceived* risks are evaluated, even when scientific evidence is inconclusive or does not indicate significant measurable impact (BP, 1997a). Thus it is apparent that social, ethical, economic and political aspects are being considered in offshore environmental assessment rather than solely physical, chemical and biological aspects. In 1998, the Royal Institute of International Affairs published a book of papers, presented at a workshop in Oslo in April 1997, that reviewed international relations and the development of the global energy industries. When writing about the 'triple bottom line' for twenty-first century business, John Elkington developed three conclusions from the Brent SPAR controversy (Elkington, 1998):

1. Companies, which believe that dealing with policy makers and regulators alone, is enough to broaden societal approval for environmentally controversial decisions are heading for a fall. Such companies will need to consult a growing range of environmental stakeholders.
2. All industrial projects – be they detergents, cars or oil platforms must be subjected to a life-cycle environmental assessment at an early stage of their development and their results must be made available to the public. New product designers talk comfortably about 'cradle to grave' assessments of consumer products, but industry still finds it

difficult to think, communicate and consult on similar terms about oil and gas platforms.

3. Environmental commitment can no longer simply be a question of investment and technology, increasingly it's about ethics and values. Stakeholders are a new category of customer and when consulted down the line they need to believe that the company is trustworthy.

4.5.6.2 Shell Exploration and Production – The 'Environmental Case'

In 1996, prior to the introduction of the Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations, 1998, Shell Expro introduced a holistic environmental assessment method called the 'Environmental Case' (Duff et al., 1997). It was proposed that there is a distinct lifecycle sequence to the offshore oil and gas field development. This sequence begins with the license acquisition, then seismic survey, exploration and appraisal drilling, design and construction, production operations and finally decommissioning. Essentially a risk-based, 'fit-for-purpose' approach, it involved applying the company's environmental management system to particular stages of a project's lifecycle. Consequently, it is a 'living' guidance document, used both for internal goal setting purposes, and as an auditable trail for regulators and stakeholders. The primary objectives of the Environmental Case were to:

- identify the potential environmental hazards from all activities and the environmental resources that might be affected
- ensure that the management system reduces and eliminates any adverse impacts and potential adverse impacts
- ensure adequate resources are available to prevent or limit damage in the event of an accident.

For each phase of the life cycle, the Environmental Case contains:

1. a description of the environment
2. a description of the activities being undertaken
3. an assessment of the potential impacts of these activities to the environment
4. a description of the prevention/mitigation/control measures proposed to minimise impacts
5. the operational management actions that are necessary to implement these measures.

This approach has a number of benefits, including:

- flexibility
- avoids duplication of effort
- consistent, risk-based, scientific approach
- transparent
- encourages a joint-industry approach to environmental assessment
- provides a coherent, structured set of information for Government and interested parties
- provides a mechanism for consultation.

The 'Environment Case' is simply an environmental casebook for a project development. It does not inform a decision-maker whether a field development is desirable or not using economic, environmental and social information. It is holistic in that it considers a cycle of activities from developing a field to decommissioning it. However, it fails to assess total environmental risk. It does not require a qualification and quantification of direct, indirect, secondary and cumulative environmental impacts, nor key linked socio-economic effects, and thus is not a system that holistically assesses environmental risks from oil and gas activities in a geographical area.

5 Holistic Environmental Assessment

5.1 *INTRODUCTION*

Since 1998 the Department of Trade and Industry (DTI) has required that Environmental Statements (ES) are prepared for new offshore oil and gas projects in the UK that are expected to produce at least 500 tonnes or 500,000 cubic metres of gas per day, and for the installation of offshore pipelines over 800 mm diameter and 40 km long. These ESs do not follow a life-of-field approach nor focus either on exploration wells (where dispensation from preparing an ES has not been granted), or production facilities and large pipeline systems. It does not include seismic surveying or field decommissioning, both elementary phases of field development. An ES will focus on the environmental burden that a proposed development will impose. It will not however assess the contribution that it makes along with other activities in the area to changing the state of the environment in the region or internationally. Tools are required that encourage environmental parameters to be engineered into field design by establishing the costs and environmental benefits of action to companies and the regions in which they operate. Chapter 4 details the need for a wider and multidisciplinary approach to current methods of analysing environmental impacts and associated costs. It is suggested in this thesis that HEA is such a process that could solve this problem.

This chapter details the HEA process framework. The proposed process is put to the test in the following chapter to demonstrate how total environmental risk may be appraised to facilitate oil and gas field development, decommissioning and planning.

5.2 *PROCESS FOR HOLISTIC ENVIRONMENTAL ASSESSMENT*

5.2.1 *Objectives*

HEA is a whole systems, goal orientated process analysis, which can be broken down into a number of stages. The process requires an analysis of both qualitative and quantitative information. Once a goal has been stated the HEA's primary objectives are to:

1. Identify all the key activities associated with the proposed field development, the probable environmental aspects that will occur and the key environmental regulation in place to control them
2. Pinpoint what technologies and techniques are already, or could be, used to minimise environmental risk cost-effectively
3. Assess total risk to the environment posed by new or increased oil and gas exploration and development in an area
4. Identify and prioritise environmental aspects of that activity to assist effective environmental liability management
5. Assess the total environmental burden associated from an environmental aspect and quantify it using environmental damage costs
6. Suggest environmental risk mitigation systems for the field development and estimate the total environmental damage associated with each
7. Forecast the cost of the designs to the operator and benefit to the environment of each and identify the most eco-efficient and cost-effective one.

The process aims to achieve this by utilising methods currently used by environmental and economic professionals. They principally include: environmental impact assessment; life cycle analysis; environmental risk assessment; environmental damage valuation; and cost benefit analysis.

5.2.2 The Goal of the Holistic Environmental Assessment

A goal needs to be clearly stated for the HEA process. It is not possible to apply the process and manage marine resources without a goal. To holistically manage oil and gas exploitation the goal is defined under the three concepts of Sustainable Development: economic prosperity; environmental quality; and, social justice. Once a goal has been set, it then becomes possible to see how the oil and gas exploration and production system has to function in order to achieve it.

5.2.3 The Stages of the Holistic Environmental Assessment Process

The HEA process is organised under three stages. The stages that make up the analysis are:

5.2.3.1 Stage 1 – Life Cycle Environmental Risk Mitigation Analysis (LCERMA)

A field development programme evaluates various types of and configurations of facilities to exploit oil and gas resources economically. The Department of Trade and Industry's (DTI) guidelines on preparing Field Development Programmes stresses the need to: minimise pollution by oil, gas flaring and venting (where technically feasible); prepare Environmental Statements; and, respect other users of the sea particularly the fishing industry (DTI, 1999e). This stage records in detail: the operations proposed for a field development; their environmental aspects; the law and economic instruments that regulate the environmental aspects; and the mitigation technologies and techniques available to drive down the risk posed by the environmental aspects. The technologies and techniques that are evaluated by HEA, include those designed to reduce environmental impact. However, those that have been developed for improved oil recovery, but which appear to have environmental benefits, are also included. From hereon the term '*technique*' is used to describe any technology, process or change in field development activities to reduce environmental risk.

It is highlighted in Chapters 2 and 3 that the greater proportion of environmental regulation of the oil and gas industry is emerging from being voluntary to statutory, and non-governmental organisations and the public influence its development. An identification of the laws that regulate the industry will indicate what the minimum environmental standards are that have to be complied with. They also provide the necessary information for any assessment of future regulatory developments. There are three phases to this stage:

- ***Phase A*** - life cycle analysis of the environmental aspects posed by oilfield development
- ***Phase B*** - identification of the legislation and economic instruments that govern each environmental aspect

- ***Phase C*** - identification of the best available environmental risk mitigation technologies and techniques, and their costs

5.2.3.2 Stage 2 – Total Environmental Risk Assessment (TERA)

This stage of the process assesses and prioritises the environmental risks of the proposed development. The assessment of environmental risk includes the key risks affecting the carrying capacity of the environment and is thus undertaken in a different way from the procedure recommended by Schedule 1 of the Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations 1999. The TERA stage then details how environmental damage can be calculated (given the uncertainty in environmental impact prediction) from economic data presented in environmental-economic studies and using probability distribution curves. The monetary values identified by this will be used later in Stage 3 to assess the environmental damage of several field development proposals each with different types of environmental risk minimisation engineered into the design. There are four phases to this stage:

- ***Phase D*** - assessment of the key risks affecting the carrying capacity of the ecosystem
- ***Phase E*** - identification of those environmental aspects generating environmental risk or benefit using environmental impact pathways
- ***Phase F*** – prioritisation of environmental aspects
- ***Phase G*** – allocation of monetary value to environmental aspects

5.2.3.3 Stage 3 – Environmental Risk Mitigation System Analysis (ERMSA)

The final stage of the HEA process identifies the field development proposal that is both eco-efficient and cost-effective. It takes the environmental damage costs identified in the TERA and, using Monte Carlo analysis to identify a damage total that can be predicted with a 95% level of confidence, applies them to the field development proposals with different types of environmental risk minimisation engineered into their design. Then the cost of mitigating against adverse environmental damage is compared with the quantified reduction in environmental damage (environmental benefit) and any risk that is not quantifiable. A sensitivity analysis is undertaken to assess the relationship between investment and environmental damage. Once a particular Environmental Risk Mitigation System is chosen, its impact on the field's economic performance can be calculated.

Few studies appear to have been carried out into assessing the costs and benefits of 'environmental protection' investments to offshore operators, other users of the sea, society and to the environment itself. This stage assesses the impact of the environmental agenda on the field development's financial statement by accounting the cost of mitigating against adverse environmental risk. There are three phases to this stage:

- ***Phase H*** - comparison of the cost incurred by the operator against the value of the environmental damage potentially incurred by society for proposed environmental risk mitigation systems, and identification of a system that is both eco-efficient and cost effective
- ***Phase I***- sensitivity analysis
- ***Phase J*** – assessment of the impact of the environmental risk mitigation cost on the project's economic performance indicators such as: net present value and internal rate of return

5.2.3.4 The Phases

A diagram detailing how the phases are implemented is presented in Table 5.1.

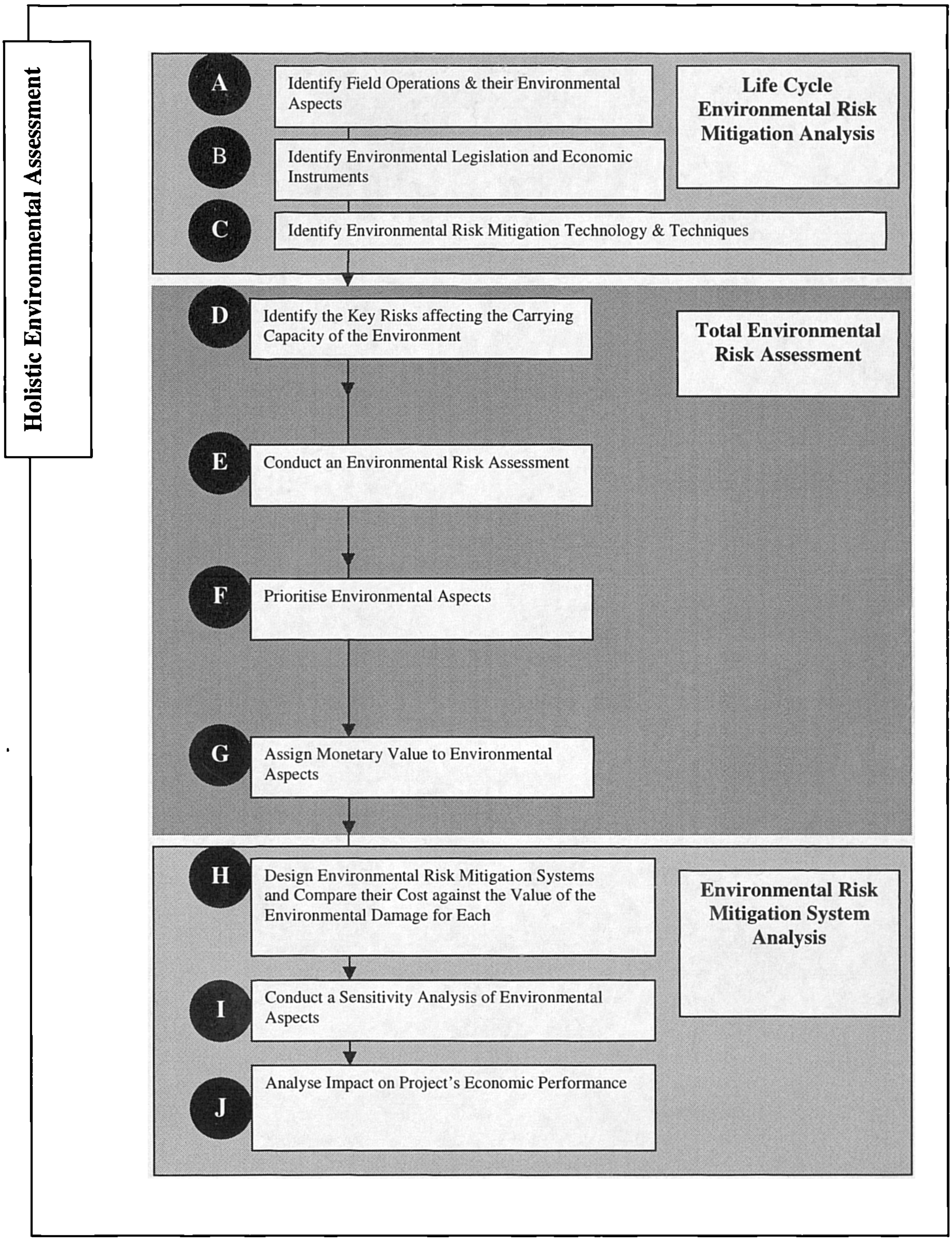


Figure 5.1. Using Holistic Environmental Assessment to Identify an Eco-efficient and Cost-effective Environmental Risk Mitigation System

5.3 *STAGE 1 – LIFE CYCLE ENVIRONMENTAL RISK MITIGATION ANALYSIS (LCERMA)*

This stage records in detail: the operations proposed for a field development; their environmental aspects; the law and economic instruments that regulate the environmental aspects; and the mitigation technologies and techniques available to drive down the risk posed by the environmental aspects. Environmental risk is dependent on the number and significance of the potential aspects of oilfield operations. Consequently the environmental aspects of operations have to be identified before any risk analysis is undertaken. Legislation and economic instruments provide identify those aspects that are likely to cause an effect that is not tolerated by society. Identifying the potential mitigation technologies that can be used to reduce adverse environmental aspects and minimisation of any subsequent environmental effects from such techniques is essential in determining the subsequent level of risk posed to the environment. The LCERMA is considered by this thesis as a strategic life cycle analysis. It does not undertake the functions of a conventional Life Cycle Analysis that details an inventory of environmental aspects and prioritises them on the basis of the quantity discharged to the environment. Instead it highlights early on in the HEA process: what is being done, i.e. what is possible; what can be done, i.e. what is probable; and what is likely to be done in the future, i.e. what potentially could be done, to reduce environmental risk.

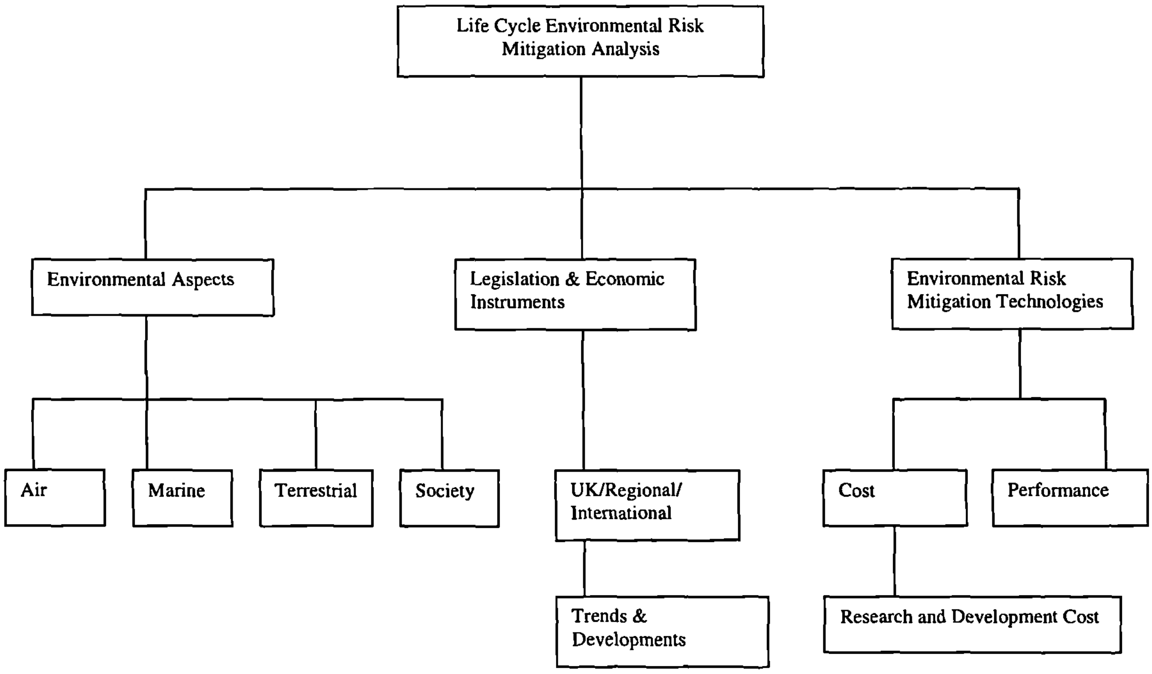
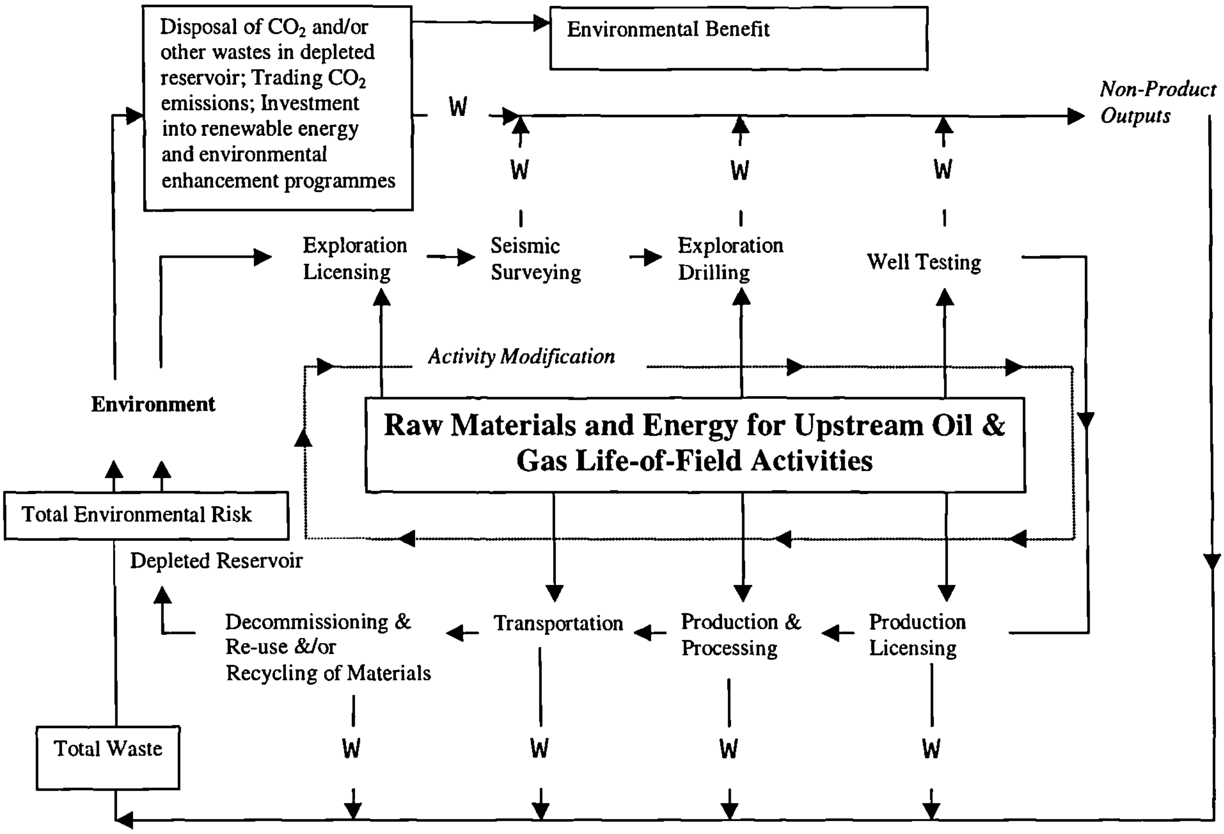


Figure 5.2. Scope of Life Cycle Environmental Risk Mitigation Analysis

5.3.1 Phase A - life cycle analysis of the environmental aspects posed by oilfield development

Environmental aspects are defined in the international environmental management system (EMS) ISO 14001 as any 'element of an organisation's activities, products or services that can interact with the environment'. A significant environmental aspect is one that produces a significant environmental impact. In this phase of the analysis all the activities involved in searching for and producing oil and gas are identified along with their environmental aspects. It is recognised that many activities in a given process occur simultaneously and this is tackled by *Phase H.* The activities are represented as a cycle and are detailed in Figure 5.3.



where: W = residuals entering the environment (this may be a positive or negative value)

Figure 5.3. Life Cycle Material Balance Model for Upstream Oil and Gas Exploitation

An assessment is undertaken to identify *which* phases in the cycle, interact with the environment by using, re-using, and producing materials and energy.

5.3.2 Phase B - identification of the legislation and economic instruments that govern each environmental aspect

The key legislation and economic instruments that govern each aspect are identified. Using a compliance manual of all the UK environmental legislation and economic instruments that cover the offshore oil and gas industry facilitates this identification. An identification of the laws that regulate the industry will indicate what the minimum environmental standards are that have to be complied with. They also provide the necessary information for any assessment of future regulatory developments. An example of this is presented in Table 5.1. This Table details the environmental law covering the discharge of oil.

Environmental Aspect	*Law*
• *Oil*	1. *Prevention of Oil Pollution Act 1971 and 1986 (As amended by The Merchant Shipping Act 1995)* - makes it an offence to discharge into the sea any oil, or oil mixture from a pipeline, or from an offshore oil and gas installation; 2. *Paris Commission (PARCOM) Decision 92/2 & the PARCOM Recommendation, Madrid, 1986* – implemented by Chapter 23 of the *Prevention of Oil Pollution Act 1971* for oil on dry cuttings and produced water; 3. *Petroleum Production (Seaward Areas) Regulations 1988* - an operator/owner is required to report the spill by sending a completed *Petroleum Operations Notice No.1.* (PON1) to the relevant authorities (HM Coastguard, the Department of Trade and Industry, and the Joint Nature Conservation Committee); 4. *The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1996* require that an installation is inspected by the Marine Safety Agency of the Department of the Environment, Transport and the Regions, and subsequently issued with a UK Oil Pollution Prevention Certificate (UKOPP) or International Oil Pollution Prevention Certificate; 5. *The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997*- since the 6 July 1998, a threshold of 15-ppm oil in water for platform drainage has been in force; 6. The *Merchant Shipping (Prevention of Oil Pollution) Regulations 1996 (1996 SI 2154) (PoOP Regulations)* as amended by *The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997(1997 SI 1910)* apply to UK Ships and distinguish oil tankers from other vessels. This legislation derives from the *International Convention on the Prevention of Pollution from Ships* (commonly referred to as MARPOL 73/78) The regulations prohibit the discharge of any oil or oil mixture into any part of the sea, unless a ship is proceeding on a voyage and is not in a special area; 7. Under *The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998* harbour operators and those dealing in oil handling, who observe, or are made aware of any event involving the discharge or the probable discharge of oil must make appropriate reports or recordings of the activity.

Table 5.1. Primary Law Controlling the Discharge of Oil into the Marine Environment

5.3.3 *Phase C - identification of the best available environmental risk mitigation technologies and techniques, and their costs*

The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations (OCIR) 2000 recommend that operators use the 'Best Available Techniques' (BAT) to reduce gas emissions from power generation. The regulations define BAT as:

a) "available techniques" means those techniques which can be implemented on platforms, balancing the costs of their implementation against benefits to the environment;
b) "best" means, in relation to techniques, the most effective in achieving a high general level of protection of the environment as a whole; and

c) "techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.

The DTI recognises that there is no procedure for identifying BAT when they state the following in the OCIR guidance notes:

"It is difficult to generalise on what represents the "best" approach for a given sector. It will be necessary for regulators, operators and vendors to work closely together to evaluate the most appropriate approach for any given oil/gas facility".

Department of Trade and Industry, 1999d

Thus there is no recommended method to assess how to balance the costs of environmental risk mitigation techniques against the benefits to the environment. An identification of those technologies and techniques that are available is undertaken. Their costs are also recorded.

As the market for Environmental Technologies grows, it is important to differentiate those techniques that will protect the environment, from those that reduce pollution in one area, only to increase it in another. The US Environmental Protection Agency (EPA) considers that there is a potential for fraud in the area of environmental technology. It has established an Environmental Technology Verification Programme to combat this risk to customers (EPA, 1999). The HEA process uses three criteria to help identify the best available techniques: mitigation management cost; proven performance/chance of success; and, technology transfer opportunities. These are detailed below.

5.3.3.1 Environmental Risk Mitigation Management Cost

There are two types of pollution costs to the operator. The costs of reducing the amount (i.e. quantity, and/or concentration) of pollution are referred to as preventative costs, and the cost that arises from remedial operations to reduce damage are referred to as restorative costs. Preventative costs are those that have been incurred directly to prevent, reduce and offset potential environmental impacts caused by routine, abnormal and accidental events. They control the risk posed by environmental aspects (the cause of pollution) and are pollution abatement costs. In this study, pollution is defined as the introduction by man, directly or indirectly of any substances, energy or species that cause deleterious effects such as: harm to living resources; hazards to human health and well-being; hindrance to other activities; impairing the quality of land, sea and/or air; and the reduction of amenities. In brief, it is any interaction with the environment that causes adverse change.

Restoration costs are the costs of cleaning-up the environment and trying to restore it to its original condition from accidental pollution. They are affected by a wide variety of factors that include extent, rate of spread, form, geographical location of the accident, and the location of resources to minimise the impact, arrest its spread and clean it up. If the actual level of damage is unacceptable to society then the polluter or those with the responsibility of clean up will be prosecuted and incur additional costs. No prosecution for failure to comply with UK environmental regulation has been made against the upstream oil and gas industry to date (Department of the Environment, Transport and the Regions, 1998). The risk of prosecution exists for as long as the law is there to regulate pollution. Thus there is no data to consider a punitive element in assessing restoration costs. Fines for marine-based disasters give an indication of the scale of restoration costs. This is because the fines imposed by the UK courts reflect the costs required to restore the environment to a state that is acceptable to society. At the Sea Empress trial in January 1999, the Cardiff Crown Court fined Milford Haven Port Authority £4 million, together with an order for restoration costs of £825,000 to the Environment Agency. This was for failing to remove the grounded tanker in the correct way and under right conditions, which resulted in the spillage of 72,000 tonnes of light crude oil to the sea and coastline (Environmental Law Monthly, 1999a).

Together, preventative and restorative costs represent an operator's expenditure to minimise environmental risk for a given project.

5.3.3.2 Environmental Risk Mitigation Management Cost, Environmental Standards and Project Economics

Figure 5.4. illustrates the relationship between cost and pollution reduction for a single pollutant. It displays the cost of complying with a legal threshold or Absolute Standard

(AS). Pollution poses an unacceptable level of risk to society below the AS. Cost-benefit theory suggests that an operator will seek to achieve the AS economically. Research in Chapters 2 and 3 suggests that it is not as clear-cut as that. European environmental regulation is developing at an accelerating rate, and with it is the uncertainty over what next, or by how much, will something else be regulated. Operators work to reduce this uncertainty by setting their own environmental standards. In the UK, these company environmental standards are higher than those forecasted by the Government. This is evident in the section on Marine Discharges in Chapter 2 where industry decided to ship oil-based mud cutting to shore for treatment ahead of the DTI's implementation of PARCOM Decision 92/2. Thus operators will seek an affordable safe minimum standard (ASMS) above that of the law. Safe is used in the context that it ensures that the environmental risk mitigation action taken now by the operator will not result in a civil liability in the future.

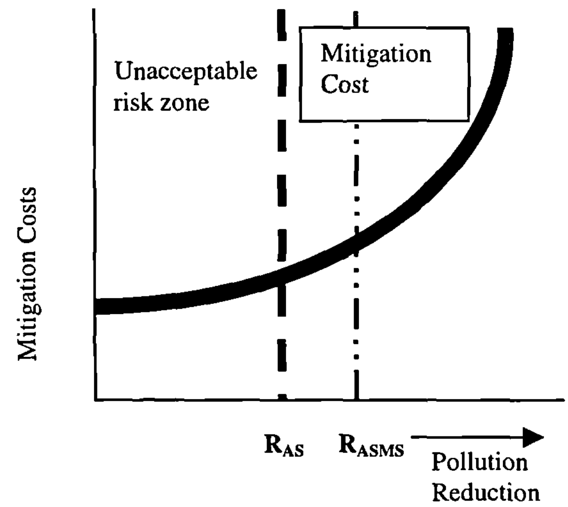


Figure 5.4. Environmental Risk Mitigation Costs
R: Reduction Level
Adapted from Munasinghe et al., 1995

The cost of action to minimise the environmental risk and achieve the ASMS is therefore dependent upon the amount of effort required to reduce risk. Figure 5.5. presents the relationship between the quantity of pollution, environmental risk mitigation cost, and oil and gas production.

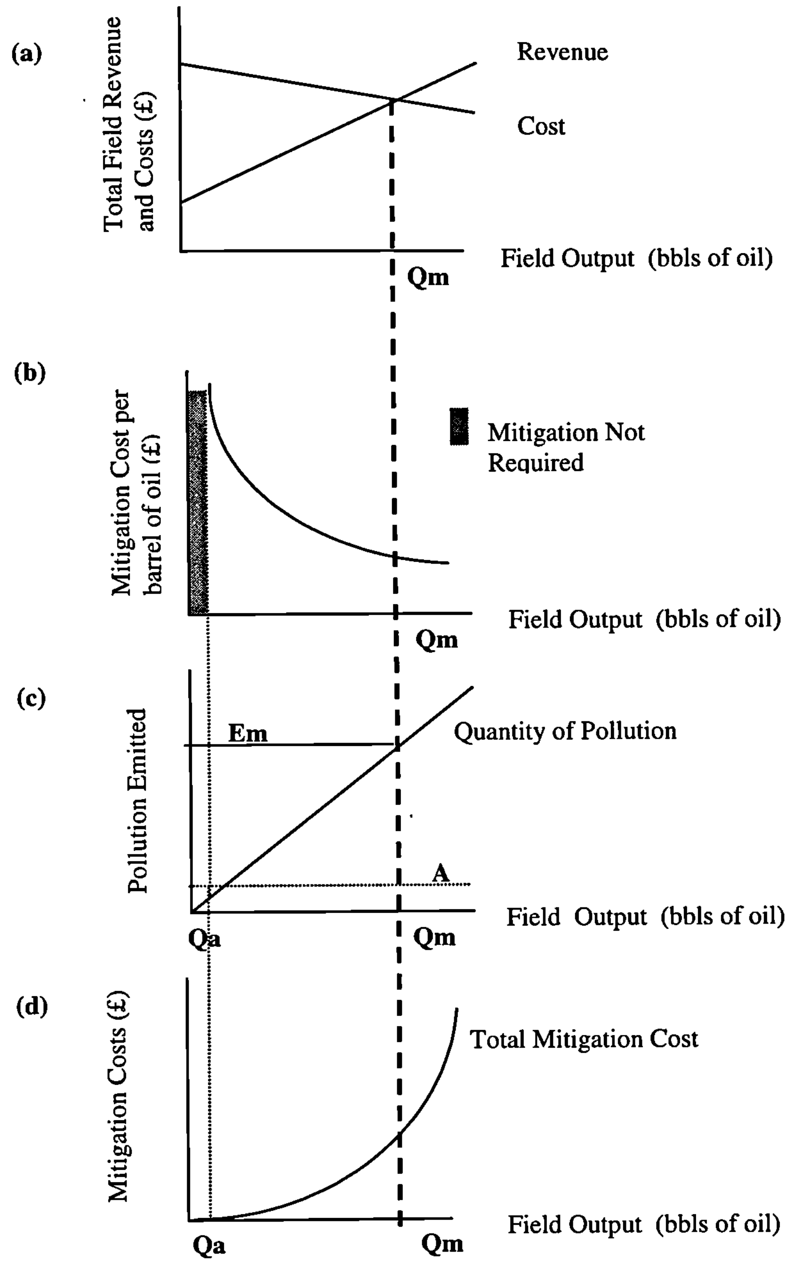


Figure 5.5. Output, Pollution & Environmental Risk Mitigation Costs
Adapted from Turner et al., 1994

(a) The basic economic aim of oil and gas field development is to extract and produce the resources at cost lower than the revenue generated by their sale. Qm is the quantity of oil produced from the field.

(b and c) As output increases the cost per barrel of oil of achieving a particular environmental standard (a set level of mitigation effort) decreases. Where the total impact is lower than the natural assimilative capacity of the environment (A) there is no reason to invest in environmental risk mitigation as any adverse impacts are short-lived and will not degrade environmental quality. As output rises so does the total quantity of emissions increase. Emissions exceed the assimilative capacity when output exceeds the quantity, Qa. When output is below Qa, the environment safely assimilates all emissions.

(d) Where an operator seeks continual improvement on an environmental standard, the increase of output of pollution (c) from an increase in production will result in a cumulative increase in total environmental risk mitigation costs.

5.3.3.3 Proven performance/level of success

Proven performance is an essential pre-requisite criterion before investing in environmental risk mitigation techniques. Techniques that have been found to achieve their targets by reducing environmental risk are favoured naturally over those that do not prevent a degradation of the environment. Establishing what techniques are commonly used offshore can help to identify those that are most likely to perform well and reduce environmental risk to a lower or negligible level. Also certain technologies that are effective at environmental risk reduction may be considered as inappropriate for particular circumstances. Assessing the probable performance of a technique or technology is dependent on field-based experience and research. For example, the use of dispersants is recognised by oil spill clean-up specialists as an effective method to reduce the environmental damage caused by an oil spill. It has been suggested that dispersants may be best suited for use in environments very sensitive to oil, but not in environments that are comparably less vulnerable (Fraser, 1989). This is because dispersants may break up the oil but they represent an additional risk due to toxicity. One of the basic questions that have to be answered before they are used is: *will the environmental risk of chemical dispersion be less than the environmental risk occurring without chemical dispersion*?

5.3.3.4 Technology transfer

There are technologies and techniques which exist to reduce environmental risk. For example a survey of techniques for reducing the risk from CO_2 emissions by lowering burden on the environment will include:

- Aquifer disposal

- CO_2 injection in depleted reservoirs
- CO_2 injection in improved oil recovery processes
- CO_2 sequestering in the form of gas hydrates
- CO_2 sequestering by algae and bacteria
- CO_2 for enhanced coal-bed methane
- Forestry
- Ocean disposal.

Not all the technologies and techniques presented above to prevent, offset and reduce environmental damage are commercially ready.

5.4 STAGE 2 – TOTAL ENVIRONMENTAL RISK ASSESSMENT (TERA)

Total Environmental Risk Assessment (TERA) is dependent upon existing scientific knowledge to assess the level of environmental risk. The risks affecting the carrying capacity of the environment and a mapping of the potential impact pathways of environmental aspects are assessed in this stage. Such an approach will minimise the possibility of overlooking synergistic effects, which tend to be absent from environmental assessments (Farmer, 1997). The stage involves carrying out a TERA to prioritise environmental aspects and identifying the economic environmental damage values that could be applied to them. In this study, such values are termed as environmental damage costs. The identification of which environmental aspects pose the greatest environmental risk is essential to reducing economically total environmental risk.

The impact of any particular environmental aspect (interaction) on the environment is inherently uncertain due to the:

a) imperfect scientific understanding of the mechanisms by which the environmental aspect influences the impact;
b) natural variation between animals and plants in the environment in terms of their reaction to a given exposure to a change in conditions;

c) variation in the levels of exposure that individual animals and plants will receive, from their temporal and spatial distribution and the random spread of the environmental aspect in the environment.

5.4.1 Phase D – assessment of the key risks affecting the carrying capacity of the ecosystem

The total risk to the environment can only be calculated by assessing the sensitivities of the environment in the region where the field development is proposed. The environmental risks that affect its carrying capacity are regional and global. These are the risks that the 'green movement' lobby the Department of Trade and Industry, and operators to reduce. These include risks such as global climate change, stratospheric ozone depletion, air pollution and the eutrophication of inland and coastal waters. Minimising the impact of activities at this level is a challenge that the Royal Commission on Environmental Pollution (RCEP) has presented to the UK in their 22nd report on energy use and climate change. The Commission states that the significant environmental risk posed by a change in climate will not be reduced by a single action but rather by adding together the actions taken by society has as a whole (RCEP, 2000). This phase focuses on the wider environmental risks that field developments contribute to, even though that contribution may be relatively small compared to other sources. Environmental risks are presented in a table and categorised under the following themes: Atmospheric Quality; Offshore Marine Environmental Quality; Coastal and Inland Environmental Quality; Biodiversity; Waste Management; Offshore Oil and Gas Field Development. The table details the environmental aspects that cause the environmental risk, the extent of the change in the environment that can be expected without any action being taken to mitigate against the adverse risks posed, and the 'outlook' that can be expected under policy measures.

Environmental Risk	*Cause*	*Extent of Environmental Change*	*Outlook*
Atmospheric Quality			
▪ Global Climate Change	*Enhanced global warming due to greenhouse gas emissions*	Climate models currently predict that annual mean air temperatures, above 1990 levels, will increase in global mean temperature of 2°C, within a range of 1.0 –3.5°C, by the year 2100, with higher increases in the north of Europe than in the south. Average sea level is expected to rise by about 50 cm, within a range of 15 - 95 cm by the year 2100. Potential consequences in Europe include increases in sea level; more frequent intense storms, floods and droughts, and changes in biota and food productivity	Seriousness of impacts depends partly on mitigation and adaptation measures. Ensuring that temperature increase at no more than 0.1°C per decade, at that sea levels rise by no more than 2 cm per decade would require European countries to reduce greenhouse gas emissions by at least 30%-55% by 2010 from 1990 levels. It is uncertain whether the EU will achieve the UNFCCC target set in 1992, of stabilising emissions of carbon dioxide in 2000 at 1990 levels, because emissions are predicted to be to 5% above 1990 levels. Furthermore, the Kyoto target of an 8% reduction in greenhouse gas emissions in 2010, the CEC's latest 'business as usual' (pre-Kyoto) system implies an 8% increase in carbon dioxide emissions between 1990 and 2010, with the largest increase (39%) in the transport sector

Table 5.2. Extract from: Key Environmental Risks affecting Carrying Capacities of the Regional & Global Ecosystem

The regional and global risks identify the core information required in the risk assessment. There is uncertainty, including, as Chapter 3 concludes, in how resilient the environment is to environmental impact. The Energy and Natural Environment Foresight Panel of the DTI identified that research into understanding the capacity of the natural environment is necessary to assess how sustainable development can be achieved (ENE, 2000).

Environmental baseline surveys, undertaken in the proposed locality of a field development, provide the local background information on natural compounds and flora and fauna required for environmental assessment. They do not provide information on the additional environmental loading of the field development in a region. For background information outside the locality such information is sparse. This lack of knowledge serves to limit our understanding of the capacities of the natural environment As a result it reduces the effectiveness of environmental assessments of the offshore oil and gas industry (OSPAR, 2000).

5.4.1.1 Marine Environmental Information Sources

Marine environmental information on the Northeast Atlantic can be obtained from UK Digital Marine Atlas Project (UKDMAP), OSPAR's North Sea Quality Status Reports (QSR) 1993 & 2000, and the 1998 European Environment Agency's Assessment of the

Environment. UKDMAP details general oceanographic information. The latter three sources identify risks to the Northeast Atlantic. The OSPAR reports identify key concerns over offshore oil and gas development. Their most recent report concluded concerns over the:

a) possible effects of disturbing drill cuttings piles;
b) lack of eco-toxicological assessment criteria and/or reference background concentrations for oil;
c) long-term impacts of the chemicals found in produced water.

Sources of information on the level of contaminants in the Northeast Atlantic seas may also be found in the above QSRs. The levels of background marine loading of natural compounds has yet to be agreed and is required to assess the degree of pollution by chemical substances and of oil (OSPAR 1993; OSPAR, 2000).

5.4.1.2 Atmospheric Environmental Information Sources

Land-based estimates of background levels of atmospheric gaseous concentrations are available from the UK's National Atmospheric Emissions Inventory. The estimates are calculated from statistical information, and are not measured concentrations. For coastal developments, estimates may be extrapolated from the nearest land-based point. The author found no data for offshore atmospheric gaseous concentrations. The National Environmental Technology Centre compiles the UK's National Atmospheric Emissions Inventory database. Such data may be used to evaluate whether emissions exceed air quality standards and hence exceed the carrying capacity of the environment. Air quality standards are detailed in the revised Air Quality Strategy for England, Scotland, Wales and Ireland (DETR, 2000).

5.4.1.3 Biodiversity Information Sources

The oil industry, under the auspices of the Atlantic Frontier Environmental Network (AFEN), has commissioned a number of independent scientific research programmes to expand knowledge of the marine flora and fauna present in the Atlantic Margin region. The information gathered resulted in the production of a biogeographical map of the largest area of seabed, ever surveyed, anywhere in the world. Two hundred sites were selected to be representative of the region. Each sample was examined for factors ranging from particle size to organic carbon and animal life – microfauna and macrofauna. This knowledge is available to any development offshore in that region to allow it to, with careful design and planning, have no more than a minimal effect on the marine environment.

The Joint Nature Conservation Committee is a forum through which the UK's three nature conservation agencies (the Countryside Commission for Wales, English Nature, and Scottish Natural Heritage) can deliver their statutory responsibilities to protect the environment. They have published a Directory of the North Sea coastal margin, which brings together information held by themselves and other conservation organisations, to provide a comprehensive account of the maritime and marine interest of the North Sea coastal zone from a UK perspective. Information has been grouped into three broad areas:

a) description of the natural environment
b) an account of the current protected status of coastal and marine habitats, communities and species
c) indication of activities which have an effect on the North Sea coastal zone

The JNCC highlight on their web-site that the general understanding of the offshore UK marine environment is relatively poor compared with the knowledge of terrestrial and freshwater environments. Consequently, the government's advisory committee on nature conservation is undertaking two new major projects to improve this knowledge. The marine information team are describing and categorising the marine life of the Celtic Coast and Seas seabed, and another, the Seabirds and Cetaceans project to catalogue and map the distribution of these organisms. Information on the marine habitats of the Celtic seas was scheduled to be available to the public in electronic format by mid-2000. The surveys of marine life were initiated by the London High Court's ruling that the UK Government had made "*a fundamental legal error*' by not applying the Habitats Directive beyond 12 nautical miles offshore (Environmental Law Monthly, 1999b). Thus it may now be concluded that the provision of such information is primarily the responsibility of a government's environmental departments and agencies.

5.4.1.4 Global Environmental Information Sources

The world's leading environmental organisation, the United Nations Environment Programme (UNEP) has recently produced GEO-2000. GEO-2000 is a review of global environmental conditions and provides those involved in environmental risk assessment and other forms of environmental appraisal with regional and global environmental risk data. The report favours a holistic approach to tackling environmental issues.

"Rather than trying to tackle issues such as deforestation and land degradation on a piecemeal basis, these must be integrated and in turn be connected with the needs and aspirations of the people".

Klaus Töpfer, United Nations Under-Secretary General and Executive Director, UNEP

Other sources of information on regional and global environmental risk include: the 1998 Independent World Commission on the Oceans report, "The Ocean Our Future", and the 1993 GESAMP's report on the Impact of Oil and Related Chemicals and Wastes on the Marine Environment.

5.4.1.5 Oil and Gas Information Sources

The DTI's chemical database SCOPEC and UKOOA's Air Emissions Inventory provide information on the contribution of environmental aspect loading from Offshore Oil and Gas activities. This data is compiled and presented yearly in UKOOA's Annual Environmental Report.

Information on oil and gas activity in the Northeast Atlantic can be obtained from Wood Mackenzie's North Sea Service. The service includes the west of Britain. The type of information available includes: licensed blocks and their operators; field; prospects including probable developments; facilities (including terminals); pipelines; and wells.

5.4.2 *Phase E - identification of those environmental aspects generating environmental risks or benefit using environmental impact pathways*

Once the global and regional environmental risks to carrying capacity have been identified, information on the risk posed by the environmental aspects of the field development is obtained. Environmental risk is dependent upon the type and potential severity of the environmental impact(s) that may be caused by the environmental aspects. ISO 14001 states that a significant environmental aspect is one that causes a significant environmental impact. It defines an environmental impact as 'any change to the environment, whether *adverse* or *beneficial*, wholly or partially resulting from an organisation's activities, products or services'. The primary aim of this section is to identify the range of potential environmental impacts for each identified environmental aspect. A single environmental aspect has the potential to cause a range of different environmental impacts. Environmental impacts take a variety of forms, and these are detailed below. These forms are categorised under key headings. These headings are based on the potential impact of an environmental aspect over time. The types of impact that occur over time are mapped under these headings as a pathway.

The pathway of an environmental impact is documented before calculation of the significance of the environmental aspect under review can be achieved. The relationship between an environmental aspect and the potential environmental impact that it causes is not a simple one. This is because there is almost always a time lag between emission and impact.

5.4.2.1 Categorising Environmental Impacts

Each type of impact in the pathway is categorised using the following definitions:

a) ***Direct*** - impacts incurred by an environmental aspect directly interacting with the environment e.g. with the actual installation of a structure, the spillage of a chemical or emission of a gas. They are acute impacts, short lived, sudden and significant, and immediately affect environmental quality.

b) ***Secondary*** - impacts arising as a consequence of the direct impacts. These are 'knock-on' effects e.g. the impact of a decrease of a species, as a result of high sudden mortality, on the ecosystem.

c) ***Indirect*** - impacts on environmental quality arising from both related activities (which can occur outside the physical extent of a development or after a development has been decommissioned), and activities of a third party (this may involve a beam trawler rupturing a pipeline or a public demonstration against a proposed development and/or provision of service). They can also result from unforeseen abnormal events arising from direct or secondary impacts.

d) ***Cumulative*** - impacts resulting from a number of different sources within a particular development or the impacts arising from more than one development in a region. These are chronic effects, which result from a continual discharge or emission, building up over time, and resulting in progressive damage of environmental quality.

5.4.2.2 Environmental Impact Pathways

The aim of the categorised pathway approach is to identify qualitatively the spatial and temporal dimensions of the impact. In essence, it is to capture the extent and number of impacts as fully as possible. The pathway documents emissions to more than just one media and maps the potential range and route of an environmental aspect. Although an environmental aspect may be emitted to the air, it may be passed onto the land or sea. It is suggested that when mapping out environmental impact pathways that the analyst recognise that it may not be possible to identify all the potential environmental impacts. However, the analysis should identify the majority of them. A summarised example of an environmental impact pathway is detailed in Figure 5.6.

Environmental Impact Assessment tends to consider the direct effects of the transport of environmental aspects over short distances such as a few kilometres, and not the implications of their wider and longer-term effects. In case studies where emissions from an activity are high, the direct transboundary effects and secondary effects have been found to be greater than the direct and localised effects. The qualitative identification of impacts from environmental aspects is achieved by reviewing the scientific literature for direct, secondary, indirect and cumulative effects. Environmental Statements and other types of environmental appraisals that are specific to the oil and gas industry are also a useful source of information. The latter two sources highlight direct effects primarily.

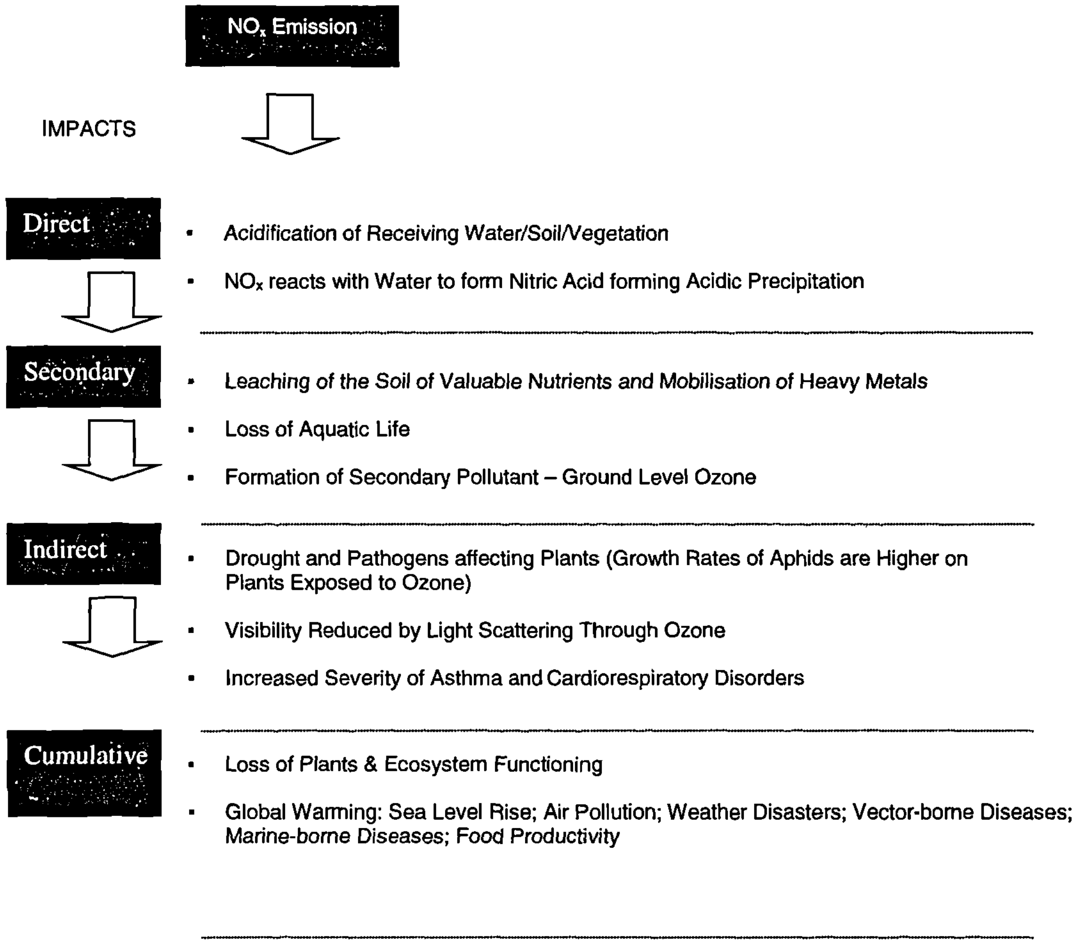


Figure 5.6. NOx Emission Impact Pathway

5.4.2.3 Impact Pathway Modelling

Impact pathways document a wide range of types of impacts. The level of risk posed by the environmental aspect is assessed in the next phase. This can only be accomplished by modelling the quantity of environmental aspect discharged to the environment and the likelihood that an impact will occur. Figure 5.6. qualifies the environmental impacts from nitrogen oxides. There is a possibility that not all of these will produce a significant environmental impact. The quantity of an aspect may be so small that the environment assimilates it with negligible net-adverse or -beneficial impact. It is essential to model the fate of environmental aspects to identify whether they will cause detectable, adverse impact. The modelling process will identify the key environmental impacts from various activities in the development of the field and those that may be considered as negligible.

There is a need to quantify, wherever possible, the environmental aspect before its impact can be modelled. Emissions to air of CO_2, NO_x, N_2O, SO_2, CO, CH_4, VOC from offshore operations can be quantified using the UK Offshore Operators Association's guidelines for the completion of an atmospheric emissions inventory. Discharges of oil to the sea can be quantified using historical information compiled by the DTI's Oil and Gas Directorate and presented in their annual report on the industry; nicknamed the 'Brown Book' (DTI, 1999f).

There is a wide range of models available to assess the dispersion of environmental aspects and their potential uptake in organisms, including man. Some are known as dose-response models. They use statistical techniques that relate differing levels of pollution (the 'dose') to differing levels of damage (the 'response'). While others map the most likely route of an environmental aspect and its behaviour in a medium, such as water. Environmental models focus on assessing direct impact and/or cumulative impact. Few models assess secondary or indirect impacts. The impact pathway attempts to represent the range of impacts qualitatively but quantitative assessment needs to be undertaken before any calculations of impact significance and the value of environmental damage are undertaken.

Research identified that there are environmental impacts that cannot be modelled on the basis that their occurrences are not fully understood. An example of this is the modelling of underwater sound and its impacts on underwater organisms. Under such circumstances, it is common practice in environmental assessment to err on the side of caution and apply the precautionary principle. There are no models available that can assess total environmental risk. This is because of the complexity and trans-disciplinary nature of environmental impact. The European Commission Externe Programme uses a range of models to assess environmental impact and calculate the damage costs for electricity generation for each Member State (and Norway) (Externe, 1998). The programme identified, during the course of analysis, that complex models were less effective at assessing environmental impact than using simple models (ibid.).

Models facilitate the environmental risk assessment process by identifying which environmental impacts are most likely to occur and at what level of severity. Following such analysis certain environmental aspects from particular activities in the lifecycle may be eliminated from the study. Examples are detailed in Table 5.3. Appendix I details the models used in the environmental assessment of offshore oil and gas operations. These could be used in a full-scale holistic environmental assessment simulation.

Environmental Aspect	***Environmental Impact***	***Environmental Models***
▪ Presence	Visual Eyesore; Marine Growth on Structure and Temporary Wildlife Haven; Temporary Exclusion Zone	ES required (Public Consultation) if distance from shore is 40km or less Biodiversity: Shannon-Wiener Index; Multivariate Analysis
▪ Heavy Metals	Toxic Effects to Organisms; Bioaccumulation and Biomagnification in Food Webs	Pollution Information Systems for Contaminants in Estuaries and Seas (PICES); Chemical Hazard Assessment and Risk Management Model (CHARM); Dose-Exposure-Response Models
▪ Noise in Water and Air	Injury or Death of Species; Animal Feeding and Breeding Disruption; Interruption and Delay in Animal Migrations; Loss of Species in a Given Area	Various propagation models available for sound travel in both air and water. No models are available to assess impact of underwater sound on the unique physiology of marine mammals and species of fish.
▪ Oily Wastes	Toxic Effects to Organisms; Ecosystem Degradation; Bioaccumulation and Biomagnification in Food Webs	Pollution Risk Offshore Technical EvalUation System (PROTEUS); Oil Spill Information System (OSIS v3.0); Environmental Management, Display and Response Operations Planning System (EMDROPS); The Shoreline Oil Cleanup, Recovery and Treatment Evaluation System (SOCRATES); Polludrome.

Table 5.3. Environmental Models to Assess Scale of Proposed Environmental Impacts

5.4.2.4 Data provided by modelling

Modelling environmental impacts will provide three key forms of data for the next phase that will help eliminate those environmental aspects that do not cause environmental impact and to prioritise those that do. These are: expected quantity of environmental aspect causing a 'response' in the environment; scale of receiving population or area; and a probability (quantitative or qualitative) of that impact occurring.

5.4.3 Phase F – prioritising environmental aspects

This phase uses the environmental information collected so far to prioritise environmental aspects. Expenditure on environmental risks that are negligible reduces the effort that must be directed at those risks that are significant. Assessing which environmental aspects do not pose environmental risk and prioritising those that do is carried out using the screening criteria detailed in Tables 5.4 and 5.5. A priority-ranking scheme has been established to identify those environmental aspects with higher relative importance. The factors evaluated are:

5.4.3.1 Type, composition and persistency of aspect in bio-sphere

The composition and type of an aspect stream determines its potential toxicity, enrichment potential and persistency in the environment. The potential toxicity level of an aspect stream and the duration that a level of toxicity will exist is evaluated in Phase E. Not all discharges and emissions are toxic to the extent that they produce lethal or sub-lethal effects. They may however exist in the environment, as waste, for a long period of time and therefore persist. Aspects that are highly toxic, able to cause nutrient enrichment, and persistent, or are inert and persistent, will pose high risk. Those that are non-toxic and will rapidly biodegrade will pose no risk.

5.4.3.2 Rate & Scale of aspect generation

The generation and/or frequency rate of aspect generation are evaluated by modelling in Phase E. High volume aspect generation will increase the scale of environmental impact, and vice versa. However, impact is also dependent upon the toxicity of the environmental aspect, which if toxic could cause deleterious effects at low volumes of emission.

5.4.3.3 Potential Adverse Environmental and Social Impacts

Section 5.4.2. highlights that a significant environmental aspect is one that causes a significant environmental impact. It is therefore the scale of and severity of an environmental impact will determine the significance of an environmental aspect. Table 5.5. details the screening process that is used to assess the significance of an environmental aspect.

5.4.3.4 Legislation, Risk of Prosecution & Public Outrage

UK society's concerns are reflected by developments in legislation. The relationship between the two is detailed in Chapter 2 and 3. Aspects that are tightly controlled require strict compliance and there are indications that this control will become tougher. Various Acts in UK Law give the Government the ability to fine polluters of the environment. Aspects that are tightly controlled by law and likely to exceed specified thresholds will pose significant environmental risk.

The environmental issues that attract public attention and cause outrage are inherently unpredictable. By identifying those issues that the public are concerned about by for instance referring to Governmental surveys (Department of the Environment, Transport and the Regions, 1998a; Scottish Office, 1991) it is possible to identify those facets of an event or issue that are likely to cause public protest.

5.4.3.5 Environmental Impact Frequency

Quantifying the frequency of environmental impacts will help determine the overall risk level. Frequency categories are assigned following a standard approach used in historical oil spill and nuclear safety risk (Royal Commission on Environmental Pollution, 1998) by Table 5.4.

Frequency	***Frequency Category***	***Definition***	***HSE Tolerability Guidelines of Risk to Workers and Public from Nuclear Power Stations****
$>10^{-2}$	5	Very likely	Not Tolerable.
10^{-2}-10^{-3}	4	Likely	10^{-3} - Just about Tolerable Risk for 'any Substantial Category (of workers) for any Large Part of Working Life
10^{-3}-10^{-4}	3	Moderate	10^{-4} - 'Maximum Tolerability Risk' for Members of the Public from any Single Nuclear Plant
10^{-4}-10^{-5}	2	Unlikely	10^{-5} - 'Maximum Tolerability Risk' for Members of the Public from Any New Nuclear Power Station
$<10^{-5}$	1	Extremely Unlikely	10^{-6} - 'Level of Acceptable Risk' at which no further improvements in safety *need be made*
* Levels of risk in terms of an individual dying in any one year. A risk of 10^{-6} is broadly the same as that being electrocuted at home and about one-hundredth that of dying in a traffic accident (Royal Commission on Environmental Pollution, 1998).			

Table 5.4. Frequency Categories

The relationship between frequency and tolerability is detailed in Table 5.4. The tolerability of an environmental risk is a balance between the benefits gained from the acceptance to receive the product or provision of service producing the risk, and the cost to the consumer of reducing and living with that risk. The maximum tolerability risk may be defined as a risk that is on the brink of being so great that it far exceeds its benefits, and/or the outcome has become ethically unacceptable that it must be refused altogether. British Nuclear Fuels plc suggested that environmental standards should be set at levels which correspond to some upper boundary of 'tolerable risk' for members of the public (Royal Commission on Environmental Pollution, 1998). There is limited information on impact statistical probabilities and levels of tolerable or acceptable risk. This is due to the diversity of environmental aspects, receiving environments and perceptions of impact severity. Acceptable and tolerable environmental risks are subtly different. If an environmental aspect poses a risk, but that risk does not exceed the risks that people accept in other contexts (such as walking across a road) then it can be regarded as acceptable.

5.4.3.6 Environmental Impact Consequence

Environmental risk requires an evaluation of both the frequency of, and consequence of environmental impact. Consequence is often termed impact severity in environmental risk assessments. Impact severity categorisations are employed in environmental statements where: 1 indicates trivial; 2, minor; 3 moderate; 4, major; and 5, catastrophic (Conoco, 1999; Agip 1999; Burlington Resources 1999 & Shell 1998b). The Department of the Environment proposed using such categorisations for assessing the significance of potential hazards on both the living and non-living environment (Department of the Environment, 1995). In holistic environmental assessment, the living environment is expanded to include effects to human health, public concern and business viability. Thus the analysis incorporates economic, environmental, legal, political and social issues. Table 5.5 defines a set of impact categories and identifies potential qualitative boundaries for significant risk.

Category	*Impact Severity*	*Sink*	*Definition*	*Risk Level*
Catastrophic	5	E	Demonstrable change in, or total eradication of, the functioning of an ecosystem, over a short or long term, or permanently.	Significant Risk
		H	The elimination of a resource, to such an extent that the well being of the persons once utilising the resource or benefiting from it, is lost. Effect causes such risk to human health and safety that the 'affected area' is no longer fit for human habitation.	
		S	Public outrage will result in extreme actions taken by individuals including demonstrations and violent attacks	
		SE	Prosecutions and restoration costs may force a company or part thereof to close down, or cause a significant decline in share value	
		NL	Destruction of geological features.	
Major/Severe	4	E	A significant change in the number of one or more species, including beneficial and endangered species, over a short or long term. This might be a reduction or complete eradication of a species, which for some organisms could lead to negative effect on the functioning of a particular ecosystem and/or other connected ecosystems.	Significant Risk
		H	Decrease in the availability or quality of a resource, to such an extent that the well being of the persons utilising the resource or benefiting from it, is affected over the long term. Effect can cause a long-lived measurable decline in human health and induces fatalities, which is not tolerated by society by means of protest.	
		S	Public outrage will result in actions including small demonstrations and complaints	
		SE	Prosecutions and restoration costs may cause a decline in company share value and/or cause a profit loss for a year to a company or affected project unit	
		NL	Any geological features are irreparably damaged.	
Moderate/ Intermediate	3	E	A significant change in population densities, but not a change which resulted in total eradication of a species or had any effect on endangered or beneficial species.	Significant Risk
		H	Decrease in the availability or quality of a resource, to such an extent that the well being of the persons utilising the resource or benefiting from it, is affected over the short term. Effect causes a short-lived measurable decline in human health, which is not tolerated by society.	
		S	Public Concern that will result in complaints.	
		SE	Prosecutions may occur and restoration costs will reduce profit.	
		NL	Damage occurs to non-living structures that are present in limited numbers.	
Minor/Mild	2	E	Some change in population densities, but without total eradication of other organisms and no negative effects on ecosystem function.	No Significant Risk
		H	Short term decrease in the availability or quality of a resource, unlikely to be noticed by persons utilising it, or those who live in the immediate area, which does not affect their well being. Aspect causes a measurable effect on human health that is tolerated by society.	
		S	Public concern may be generated however complaints are unlikely.	
		SE	No prosecutions however some restoration costs may be incurred.	
		NL	Damage occurs to non-living structures that are commonplace.	
Trivial/ Negligible/ Minimal	1	E	No significant changes in any of the populations in the environment or in any ecosystem functions.	No Significant Risk
		H	Short term decrease in the availability or quality of a resource, unlikely to be noticed by persons utilising it, or those who live in the immediate area, which does not affect their well being. Aspect does not cause a measurable effect on human health in the short or long term.	
		S	Public perceive environmental impacts to be of no concern.	
		SE	No penalty costs incurred by company, as no prosecution or restoration action is required.	
		NL	Very slight damage occurs to non-living structures that are commonplace.	

Table 5.5. Environmental Impact Categories

Key: E – Ecological; H – Human; S – Societal Perception; SE – Socio-economical; NL – Non-Living (includes geological and man-made structures)

Adjustments are made to reflect the impact of environmental aspects occurring in areas of particular sensitivity or insensitivity. For example if the activity under analysis is occurring in an area of environmental sensitivity then an impact severity category will increase by 1. If on the other hand, the activity under analysis occurs in an area of low sensitivity, (for example – the environment is resilient to perturbation) the environmental impact category will be decreased by 1.

5.4.3.7 Risk Assessment

Having assigned the frequency and consequences of an environmental aspect, it is then assigned a risk index from Table 5.6.

	Frequency				
Consequence	*Extremely Unlikely*	*Unlikely*	*Moderate*	*Likely*	*Very Likely*
Catastrophic	5	10	15	20	25
Major/Severe	4	8	12	16	20
Moderate/ Intermediate	3	6	9	12	15
Minor/Mild	2	4	6	8	10
Trivial/Negligible	1	2	3	4	5

Table 5.6. Risk Index

The equation used to derive the risk index in Table 5.6 is as follows:

$$\text{Environmental Risk} = F \times C \qquad (1)$$

Information provided on the basis of the equation can be used to prioritise environmental issues and thereby help identify which require mitigation.

Activity	Environmental Aspect	Environmental Burden	Impact Severity	Frequency	Risk Index
▪ Seismic	▪ Seabed Disturbance	No known disturbance	-	-	-
		Disturbance predicted if OBC used throughout block area	2	5	10
	▪ Persistent Waste to Sea or Land	Special Waste: >5 te	3	5	15
	▪ Disturbance	2 months/100 km^2	1	4	4
	▪ Sound in the Water	222 dB rel 1µPa @ 1m – Shot at 25 m intervals	3	5	15
		Delay P(0.1): Out of 174 gun starts ups, 19 resulted in operation delay**			
	▪ Sound in the Air	No data identified	1	5	5
	▪ Hydrocarbons Released to Sea	Variable	3	5	15
	▪ Introduction of Foreign Species from Ballasting	Not Quantifiable	2	1	3
	▪ Chemical Discharges	-	-	-	-
	▪ Sewage & other Facility Wastes	Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person;	2	5	10
	CO_2	5760 te/60 days*	3	5	15
	▪ CO	14.4 te/60 days	2	5	10
	▪ Oxides of nitrogen	106.2 te/60 days	3	5	15
	▪ SO_2	7.2 te/60 days	3	5	15
	CH_4	Negligible	1	5	5
	▪ Particulates	No data identified	-	-	
	▪ Social Interaction	30-40 people at sea	nq	nq	nq
		Fishing Industry	2	5	10
* Seismic vessel requires 30 tonnes of fuel/day					
** Data from field trials of passive acoustic monitoring offshore (Gordon et al., 2000).					

Table 5.7. An Example of a Risk Assessment of Seismic Survey

The risk index shown in Table 5.7. is against the As Low As Reasonable Practicable Paradigm (ALARP) developed for determining levels of safety by the UK Health and Safety Executive. It provides a hypothesis to test for the remaining stages of the process. Section 5.3.3.2 highlights the fact that increasing investment will reduce pollution and, therefore, that investment produces a benefit for the environment.

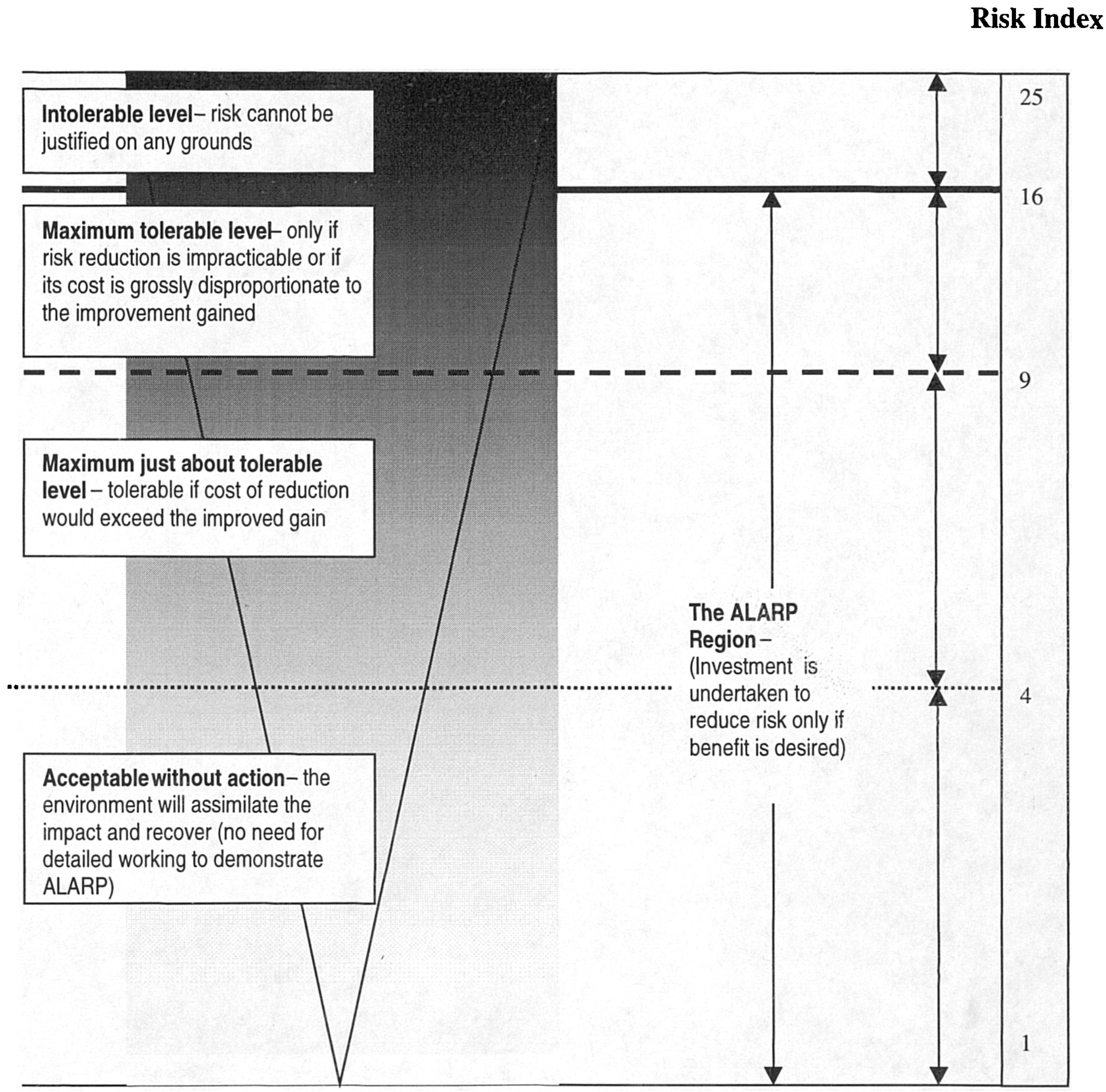


Figure 5.8. Incorporating the ALARP Principle

5.4.4 Phase G – allocation of monetary value to the significant potential environmental impacts

5.4.4.1 Environmental Damage Costs

The above section provides the analyst with a list of environmental aspects that have been prioritised according to the environmental risk that each of them pose. The risk indices are independent and mutually exclusive values and as such cannot be aggregated to a value that represents the total environmental risk that the development poses. Environmental risk can be quantified using environmental damage costs. Environmental damage costs are externalities. They are the costs imposed on society that are not accounted for by the producers and consumers of energy. The costs however, are not traded in the market. They are valued by a variety environmental-economic methods, which include: the Travel Cost Method; the Hedonic Valuation Method; the Shadow Project Method; the Contingent Valuation Method; and Indirect Valuation Method. HEA uses environmental damage costs from contingent and indirect valuation. The Contingent Valuation Method (CVM) is a survey-based approach that asks individuals to value environmental quality. Values from these contingent valuation studies assess the amount individuals are willing to pay (WTP) to avoid the environmental damage. One of the major limitations of contingent valuation studies is the complexity of the good being valued. It is considered unreasonable to expect respondents to give satisfactory valuation of a good which they do not understand or have an extremely limited knowledge (Side & Kerr, 1996). Some economists consider contingent valuation to be a deeply flawed method of environmental valuation and unsuitable for damage assessment, whilst others consider that, *whilst understanding the limitations of contingent valuation*, if conducted properly, such studies are one way of consulting the relevant experts – the public itself (Diamond & Hausman, 1994; Hanemann 1994; Portney 1994; Turner et al., 1994). The author discovered that expert judgement is the only other alternative to assess environmental risk. The Indirect Valuation Method (IVM) calculates the dose-response relationship between pollution and environmental impact. They value the relationship between the dose (pollution) and the non-monetary effect (low crop productivity or the impact of rising levels of particulates on health services in cities, for example). Traditional cost benefit analysis (CBA) has tended to ignore these costs. However, the use of externalities in CBA is increasing, and is referred to as Environmental Damage Valuation (EDV). EDV is being undertaken particularly in real estate appraisals in the US (Damage Valuation Associates, 2000).

Assessing externalities requires an assessment of: how much damage has been caused; how much individuals are willing to pay to avoid that damage; and, how much individuals are willing to accept to get by with that damage. An example of an externality is a situation in which an individual or firm takes an action that reduces or increases the value of an environmental resource, but does not bear all the costs (negative externality) or receive all the benefits (positive externality). Instead a third party bears the costs. Sustainable Development implies that environmental resources have value even when they are not presently being used.

A polluter will react to external costs imposed on him either by modifying his production or consumption process to make it less polluting and passing the cost on to the consumer, or by moving away, whichever is economically favourable. External costs may be further reduced by the relocation of pollution recipients, or by altering their activity in the affected location or by being involved in damage-reducing activities such as clean up or conservation programmes. Costs may be further complicated by the availability of many combinations of these alternatives.

5.4.4.2 Factors affecting the Damage Costs

The type and extent of environmental damage will affect the value of externalities. Table 5.8. details the relationship between offshore oil and gas environmental aspects and the changes that may occur in affected environmental resources. When assessing damage cost the type of change to the environment that can occur must be identified and then evaluated economically.

Environmental Aspect	*Environmental Impact* *	*Environmental Resource*	
		Type of Environmental Change	**Factor(s) affecting Level of Environmental Change**
▪ Presence	Visual Eyesore; Marine Growth on Structure and Temporary Wildlife Haven; Temporary Exclusion Zone	Coastal Property Value; Number of Visits to Park; New Species; Effect on Biodiversity; Effect on Fishery Catch	Development Design;Duration of Activity; Coastal Land Use; Depth and type of Substrate; Location; Distribution of Commercial Fish Breeding and Spawning Locations; Fish Migratory Routes
▪ Heavy Metals	Toxic Effects to Organisms; Bioaccumulation and biomagnification in food webs	Species Loss; Effect on Human Health	Success of Uptake through Food Chain; Dose Response Relationship
▪ Noise in Water and Air	Injury or Death of Species; Animal Feeding and Breeding Disruption; Interruption and Delay in Animal Migrations; Loss of Species in a Given Area	Species Loss	Type of Species & Public Concern; Breeding and Feeding Areas; Migratory Routes
▪ Oily Wastes	Toxic Effects to Organisms; Ecosystem Degradation; Bioaccumulation and biomagnification in food webs	Species Loss; Habitat Loss; Effect on Human Health	Quantity and Discharge Rate of Oil; Type of Oil; Sea State; Water Depth; Availability of Microbes to Biodegrade Oil; Availability of Dissolved Oxygen on the Seabed; Type of Species & Public Concern; Type and Importance of Ecosystem to Other Users; Success of Uptake through Food Chain; Dose Response Relationship

* Environmental Impacts are identified by pathway analysis in Phase E.

Table 5.8. Modelling the Relationship between Environmental Aspects and the Change in Affected Environmental Resources

Environmental damage data are obtained from scientific journals, the Canadian Environmental Valuation Resource Inventory (EVRI) and European Commission's ExternE programme, and presented in *Look-up* tables in Appendix II. The use of the EVRI in this way to calculate environmental damage costs from polluters is recommended by the European Commission in their White Paper on Environmental Liability (European Commission, 2000). These tables contain the abstract of the valuation study to ensure that the values are correctly used in a circumstance similar to that in which the study was conducted. An abstract will also highlight other data and issues that an evaluator will need when assigning values to environmental aspects and their impacts. Examples of data are detailed in the Table 5.9.

Environmental Aspect	Measurable Value	Damage Value £2000	Location of Valuation Study
Marine Environment			
▪ Oil	Species Loss and/or Decline; Habitat Loss or Degradation; Human Health; Public Complaints	14-4,582 for ecological habitat/ te oil discharged/spilt to sea. Values incoporate temporal and spatial variations	USA
▪ Chemicals	Species Loss and/or Decline; Habitat Loss or Degradation; Water Quality Decline; Human Health; Public Complaints	6-23 for ecological habitat/te chemical mixture discharged to sea	USA

Table 5.9. Environmental Damage Cost Data

The damage costs presented in this thesis have been taken from studies undertaken in economically developed countries and are converted to Year 2000 British Pounds/tonne. Table 5.9. presents the environmental damage costs as ranges. These ranges are the lowest and highest identified valuations for the environmental aspects. This is because the studies researched identified that the majority of environmental aspects caused different levels of damage cost, or tend to be valued differently by analysts thereby producing a range of results. Environmental aspects are presented by single values where this was not the case.

5.4.4.3 Calculating Environmental Damage Cost Using the Quantity of an Environmental Aspect

A number of linear equations are used to calculate environmental damage. Environmental aspects will either occur from routine operations or as a result of an accident. Environmental damage costs for environmental aspects that occur as a matter of routine are calculated by multiplying the total quantity of environmental aspect by the per unit damage cost. Those that occur from accidents are multiplied by the probability of that accident occurring. Offshore oil and gas accidents that produce a major environmental impact have been statistically proven to be the same as those for commercial airlines (Sharples, 1992). For this reason it is considered that the expected environmental damage from accidents will be small in comparison to routine activities. Equation (2) can be used to compute the expected damage value for a series of environmental aspect streams:

$$EDV(tot) = \sum_{i=1}^{n} Q_i.p(Q_i).P_i \quad \text{(where i = 1,2....n)} \tag{2}$$

where Q = expected quantity producing an environmental impact (tonnes)

$p(Q)$ = probability of Q occurring

P = economic value of environmental impact (£)

EDV = environmental damage valuation (£)

There are environmental aspects that cause enhanced global warming but their economic impact has not been valued. Their Global Warming Potentials for 100 years (GWP) are used to overcome this. The GWP is multiplied against the economic value of the environmental aspect from which they were computed, for example carbon dioxide. This is presented in equation (3).

$$EDV(tot) = \sum_{i=1}^{n} Q_i.p(Q_i).P_i.GWP_i \quad \text{(where i = 1,2....n)} \tag{3}$$

where Q = expected quantity producing an environmental impact (tonnes)

$p(Q)$ = probability of Q occurring

P = economic value of carbon dioxide (£)

GWP = Global Warming Potential

EDV = environmental damage valuation (£)

5.4.4.4 Calculating Environmental Damage Cost Using the Concentration of an Environmental Aspect

For those environmental aspects that produce an effect that is not dependent upon an emission quantity but the concentration of a pollutant, an alternative equation is adopted. The value of damage will be dependent upon the effect and the humans, animals and plants at risk from that effect (Pearce & Crowards, 1996). Each effect, E_i, has an economic value P_i, so that:

$$P_i.dE_i = P_i.b.POP_i.dA_j \tag{4}$$

where b = slope of dose-response or exposure-response function

POP = humans, animals and plants at risk from effect, i

A = ambient air quality

j = jth pollutant

and the sum of damages, *EDV*, from pollutant j is:

$$EDV(tot) = \sum_{j=1}^{n} P_j.dE_j.p(E_j) \qquad \text{(where } j = 1,2....\text{n)} \qquad (5)$$

b in equation (4) is the slope of the dose-response or exposure-response function. b could begin at some point threshold value below which no damage is done. According to Pearce and Crowards study into the effects of particulate matter on human health no firm evidence for thresholds for air pollutants appears to be available. This conclusion is adopted following evidence in their study that health effects, including fatal effects, still exist below EPA and WHO recommended thresholds, and effects that are difficult to detect may continue to occur at lower concentrations. For this reason, a working assumption is adopted that the dose-response or exposure-response function commences at the origin.

5.4.4.5 Calculating Environmental Damage Cost in the Absence of Measure of Environmental Effect

For those environmental aspects that produce an effect that is not dependent upon a specific quantity of discharge or a diluted concentration but a particular action or management principle adopted by an operator, an alternative equation could be used to calculate environmental damage. Environmental effects (E) from disturbance, sound, public outrage, and light, are examples of this.

$$EDV(tot) = p(E_i).POP_i.P_i \qquad (6)$$

where $p(E)$ = probability of E occurring

POP = humans, animals and plants, or scale of receiving environment (km) at risk from i

P = economic value (£)

EDV = environmental damage valuation (£)

5.4.4.6 Plotting Environmental Damage Valuations

Section 5.4 highlights the key factors that contribute to the uncertainty inherent in the consequences of any particular environmental aspect (interaction) on the environment. The uncertainty in damage cost data used to assess the magnitude of environmental impact increases this uncertainty.

Uncertainty involves notions of chance, risk, hazard and unpredictability. The concept of probability is the most useful basis for expressing uncertainty, and is the basis for statistically analysing data. The application of statistical methods pervades all areas of science, engineering, economics, market research and business management. In all cases the impetus for its use is to extend understanding in the face of uncertainty and variation, and in situations that require decision-making, to derive cost effective and defensible actions. In 1997 the Royal Commission on Environmental Pollution commissioned the Department of Mathematics at the University of Nottingham to prepare a report on handling uncertainty and variation in environmental standard setting. The authors concluded that statistical methods are essential for measuring probabilities and for making inferences and decisions in the face of uncertainty and variation to all aspects of environmental pollution control (Barnett and O'Hagan, 1997).

In HEA the uncertain variable is environmental damage cost. Section 5.1.4.2 presents the damage costs as ranges. The environmental damage cost for a particular environmental aspect from offshore oil and gas development can be predicted with 95% confidence by plotting the probability for the range of damage costs using the cumulative distribution function of the aspect's environmental damage values.

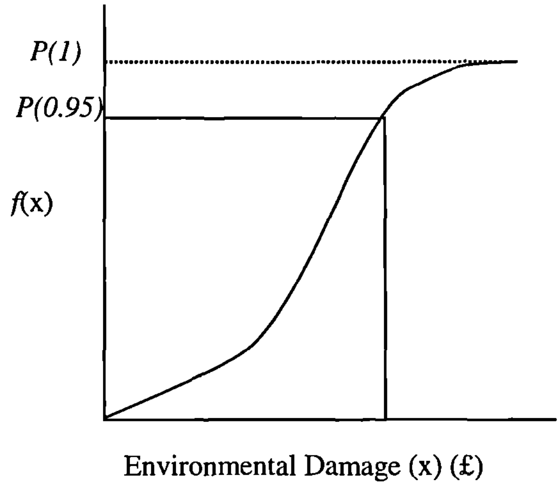


Figure 5.9. The Cumulative Distribution Function (x)

The density distribution of x, or Normal distribution can be plotted by differentiating the distribution function to represent the relative probability curve of damage costs. The bell shaped curve is commonly used. Given two values x_1 and x_2, the probability that the true value of x will lie between x_1 and x_2, is the area under the curve (see Figure 5.10.). Since x is certain to have some level of probability, the area under the entire curve must be equal to one. The standard deviation is a measure of the variability of data. The zone defined by one standard deviation on either side of the mean of a normally distributed damage cost variable will contain 68.26% of the distribution. The zone that is defined by the standard deviation multiplied by 1.96 contains 95% of the distribution.

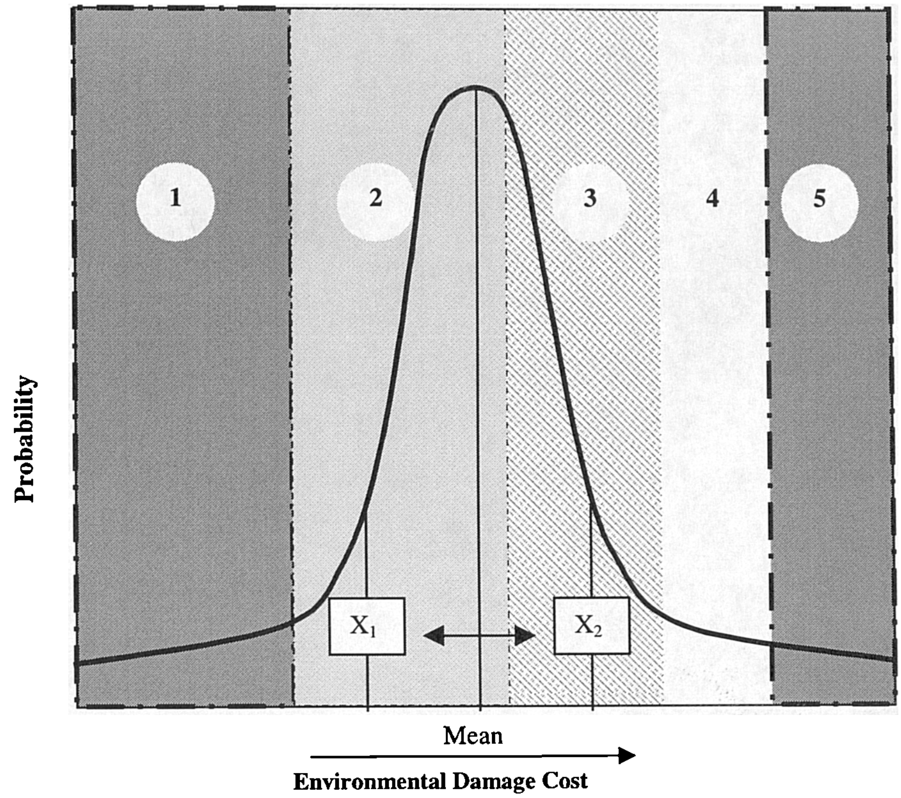


Figure 5.10. Normal Environmental Damage Valuation Curves for a Specific Environmental Aspect with Impact Severity Categorisations

Not all interactions with the environment from field development occur as a matter of routine. Interactions can also occur from accidents. Accidents offshore include oil spills, the venting of gas from a kick, or the spillage of drilling or production chemicals. This increases uncertainty about environmental damage. The level of uncertainty is influenced by the probability of whether or not a large-scale interaction with the environment will occur. A distribution is required to reflect this variance in event probability. A log-normal distribution is chosen to represent accidental events. The probability of a value x being less than the mean is higher than the probability of x being higher than the mean. This reflects the probability of major accidental events. Major oil spills have been demonstrated by historical oil spill data to be very rare whereas minor oil spills are more common. In 1997 the Advisory Committee on Oil Pollution of the Sea (ACOPS) identified that the greatest number of accidental oil spills is small. Analysis of 1996 UK offshore oil and gas E&P statistics showed that 53% of an estimated 300 spills were less than 455 litres (ACOPS, 1997). Plotting the probability of such events will result in an asymmetrical or skewed distribution where the mean, median and mode tend to spread out. A log-normal distribution curve is detailed for the environmental damage from an accidental environmental aspect is detailed in Figure 5.11.

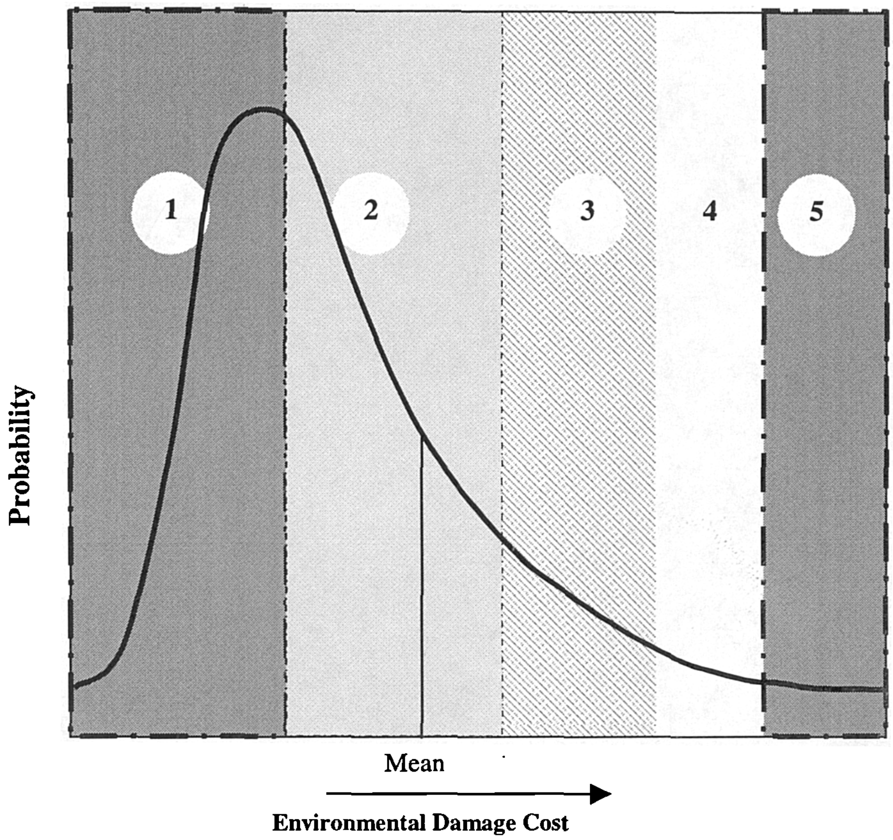


Figure 5.11. Normal Environmental Damage Valuation Curves for a Specific Accidental Environmental Aspect with Impact Severity Categorisations

The Environmental Impact Severity Categories are displayed in Figures 5.10. and 5.11. for illustrative purposes. Their position will change depending on the environmental aspect.

5.5 STAGE 3 – ENVIRONMENTAL RISK MITIGATION SYSTEM ANALYSIS (ERMSA)

The previous section presents an explanation of how to calculate and plot environmental damage costs. This section demonstrates how that information can be combined by Monte

Carlo Analysis to calculate the total environmental damage cost of proposed field developments.

Research undertaken during the course of this study identified that it is not common practice for operators to record and publish their expenditure on environmental management. Although, a few operators were recording these expenditures, detailed environmental accounts were not available to the author. This section proposes the establishment of an environmental accounting system using Monte Carlo Analysis. The system is used to analyse different field development environmental risk mitigation systems and identify the total environmental risk and cost to the operator of each.

5.5.1 Phase H - comparison of the cost incurred by the operator against the value of the environmental damage potentially incurred by society for proposed environmental risk mitigation systems, and identification of a system that is both eco-efficient and cost effective

The results from the environmental risk assessment Section 5.4.3.7 prioritised environmental aspects on the basis of a risk index. Environmental risk mitigation systems for a field development are then designed, with the greatest attention being placed on those environmental aspects that present risk at an intolerable risk level according to the ALARP principle. The total environmental damage reduced or increased by the techniques implemented to reduce environmental risk is calculated. The cost of reducing environmental risk posed by the occurrence of an environmental aspect is calculated in order to assess the cost of environmental risk mitigation. Cost data combined with the change in the environmental damage cost will indicate whether the investment is worth the environmental benefit gained. This may appear obvious, but as stated section 5.3.3, there is no environmental technology verification programme in the UK that assures operators that the techniques they are using reduces the total environmental risk, and minimises the environmental liability, of their operations.

The procedure for calculating the cost of mitigating environmental risk is holistic. It considers the cost of reducing the burden on the environment, from seismic survey to decommissioning, and possibly to the subsequent use of depleted wells for waste disposal. Mitigation cost for each of the prioritised environmental aspects across the whole life cycle of the field development is calculated. Mitigation costs, as described in Section 5.3.3.1 are either *Preventative Costs*, i.e. costs incurred to prevent, reduce or offset environmental impacts, or *Restoration Costs,* i.e. costs that will be incurred once an environmental impact has occurred.

$$C(tot) = \sum_{i=1}^{n} [C_i + (O_i.t)] \text{ (where } i = 1,2....n) \quad (7)$$

where: i = technique

C = capital cost of technique (£)

O = yearly operating expenditure (£)

t = number of years

Alternative equations are used where the cost data is presented either as a fraction of oil throughput or the amount of waste treated or recycled:

$$C(tot) = \sum_{i=1}^{n} C_i.P_i \quad \text{(where } i = 1,2....n) \quad (8)$$

where: i = technique

C = cost of technique per barrel of oil produced (£)

P = total probable oil in place

or,

$$C(tot) = \sum_{i=1}^{n} C_i.EA_i \quad \text{(where } i = 1,2....n) \quad (9)$$

where: i = technique

C = cost of technique per unit aspect produced (£)

EA = total amount of environmental aspect to be treated

In situations where the technique to reduce environmental risk is based upon upgrading or changing the way an operation is performed, such as changing a drilling mud from oil-based to water-based, the difference in cost is considered by the HEA process as environmental expenditure.

A mitigation accounting procedure is constructed rather than on the basis of the phases of the development. This is problematic, as many phases of a field development overlap and the actions to mitigate adverse environmental risk do not necessarily occur in the order suggested by the lifecycle detailed in Figure 5.12. For example, wells may be drilled during the course of production to enhance recovery from a field. The figure below, however, represents a useful overview of the environmental risk mitigation costs and their relationship with the life cycle of field development.

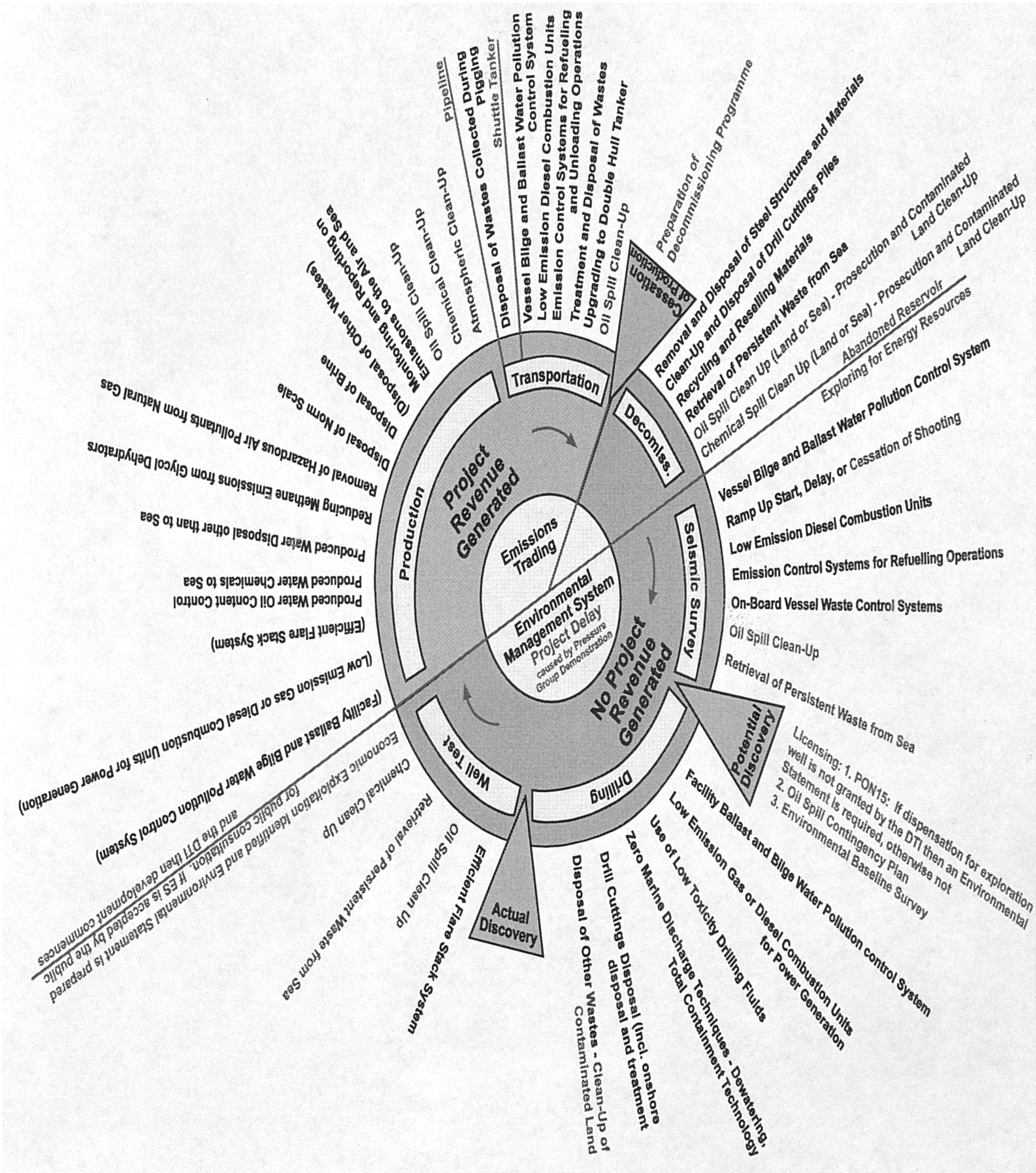


Figure 5.12. Lifecycle of Potential Preventative and Restoration Environmental Mitigation Costs for an Oil Field

In parenthesis: indicates action that may have been already undertaken

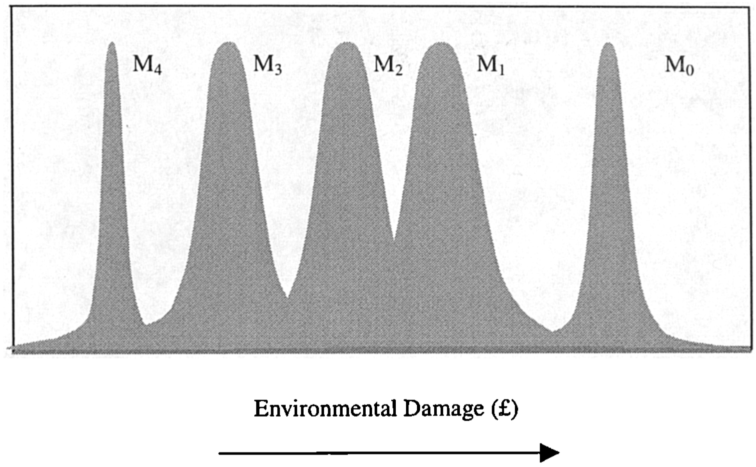
Each particular environmental risk mitigation design for a field development will have a specific cost. Expert judgement should inform the operator that the more that is spent in mitigating environmental risk then the greater the benefit to the environment. The hypothesis in section 5.4.3.7 suggests that investment into mitigation will produce environmental benefit.

The damage costs for routine environmental impacts are plotted as normal distribution curves. Normal distribution curves are chosen, as any uncertain variable could as likely be above the mean as below it (i.e. symmetrical about the mean, see Figure 5.10). A LogNormal Distribution is used to evaluate accidental impacts because the values will be positively skewed. The full explanation of the choice of curves is detailed in Section 5.4.4.6.

The Normal and LogNormal Distributions curves of damage costs are converted into cumulative probability distribution curves, and combined using Monte Carlo Analysis to compute total environmental damage cost. These are also known as 'expectation curves' in the analysis of oilfield reserves. The environmental damage expectation curve is plotted as positive because whatever mitigating action is taken, there will always be some level of damage (Figure 5.13.). For a particular system of mitigation we can assert, with a prescribed probability of 95% from the cumulative distribution curve that the level of environmental damage is *x*, or *y*, (Figure 5.14c.). This value is the level of environmental damage that should not be exceeded with a probability of no more than 5%, 0.05. The environmental benefit value for each environmental risk mitigation action for a particular environmental aspect can be calculated. This is achieved by subtracting the reduced environmental damage cost of an environmental aspect (as a result of that action) of one system from the environmental damage for the system where no action has been taken to mitigate against its environmental risk. Figures 5.14c, d & e detail this relationship.

A project with no environmental risk mitigation (M_0) will cause significant environmental damage. Whereas a project that invests heavily in environmental risk mitigation (M_4) should, provided the right investment decisions have been made, will cause much less environmental damage.

(a)



(b)

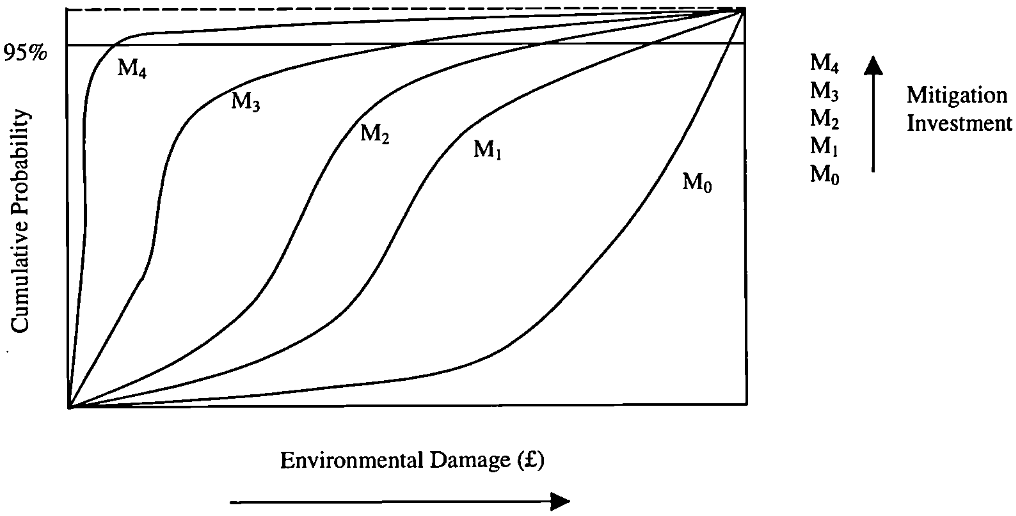


Figure 5.13. Different Levels of Mitigation and Environmental Damage

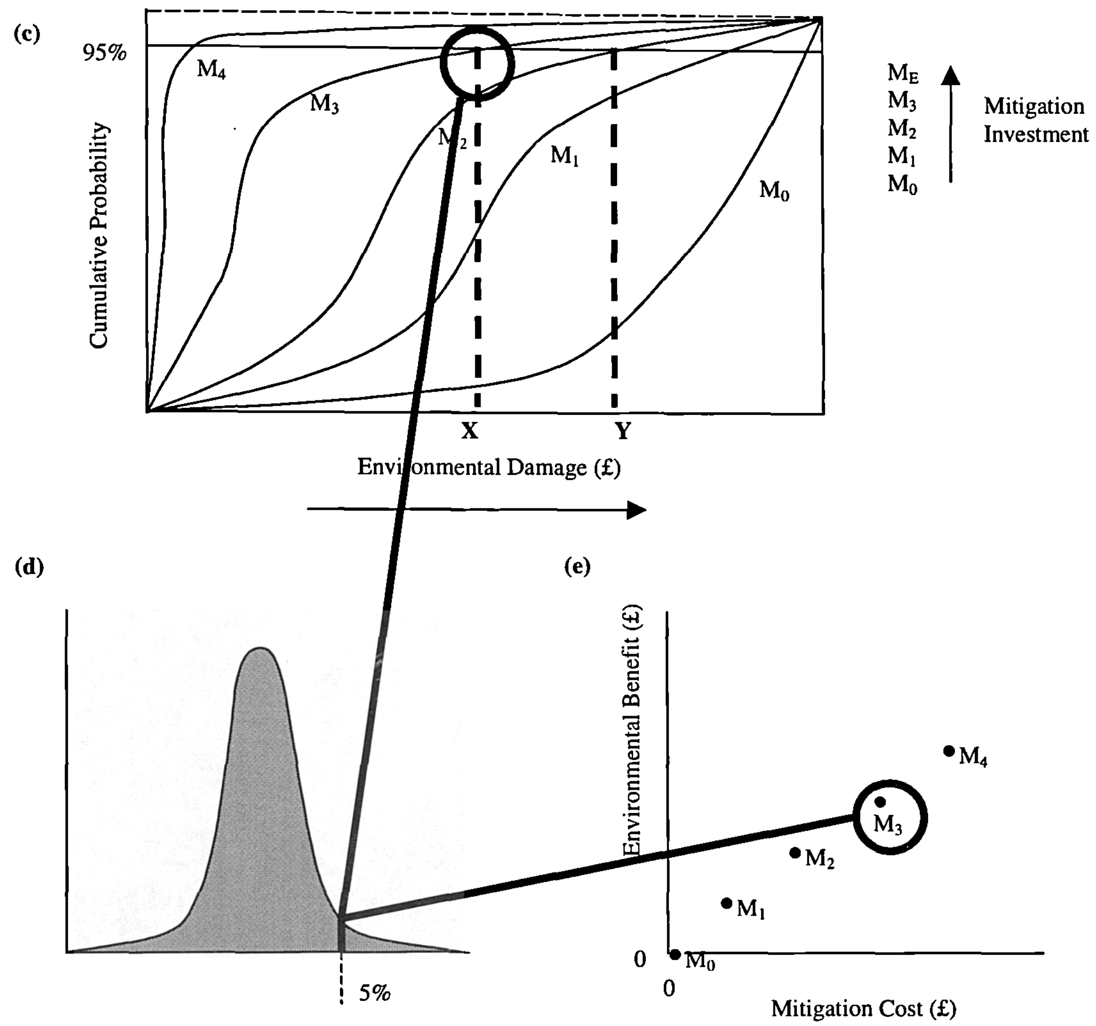


Figure 5.14. Identifying the Level of Environmental Damage and Benefit for each Environmental Mitigation Risk System

Under certain circumstances, action taken by the operator to reduce environmental risk, such as the implementation of an environmental management system, will influence more than one environmental aspect. It is therefore difficult to determine an accurate cost of risk mitigation for each environmental aspect.

5.5.1.1 Monte Carlo Analysis

Monte Carlo Analysis (MCA) has become a standard technique used in the assessment of the environmental impact of a given level of pollution with full analysis of attendant uncertainties (Barnett & O'Hagan, 1997). It is useful in HEA because it can be used to evaluate a large number of samples, or eventualities for each environmental aspect. MCA picks a random number (between 0 and 1) and the associated value of environmental damage cost for each environmental aspect of an *Environmental Risk Mitigation System* is read from the range detailed in the distribution. This is repeated 1,000 – 10,000 times, with each outcome being equally likely. The more sets of combinations are made of the two variables, the closer the Monte Carlo result will be to the theoretical result of using every possible combination. It must be remembered that the result is only a combination of the ranges of input variables defined by the user; the actual outcome could lie outside the simulation result. The outcome cannot be guaranteed to be the same when the simulation is run twice and the same input variables are used. This makes the result less auditable.

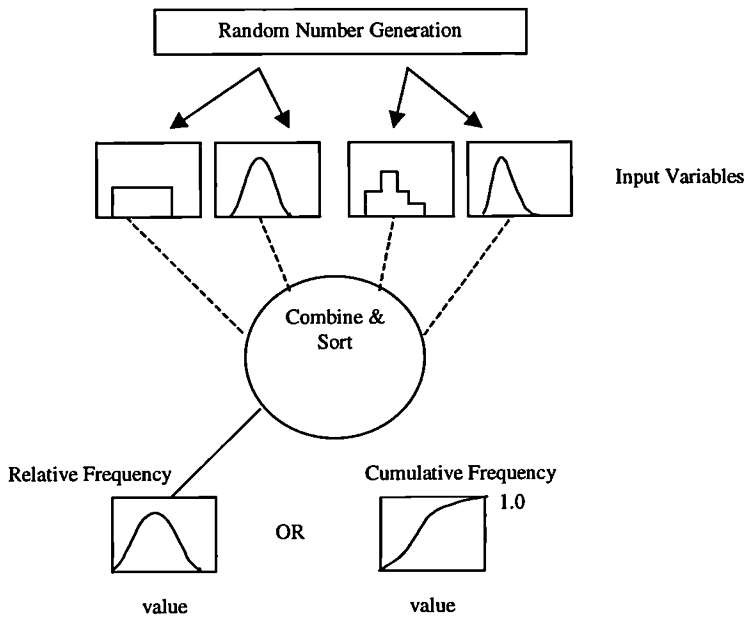


Figure 5.15. Schematic of Monte Carlo Simulation
Source: Jahn, Cook & Graham 1998

The computed outcome is the total environmental damage cost for each Environmental Risk Mitigation System (ERMS). The total environmental benefit value for each ERMS can be calculated by subtracting the environmental damage cost for those fields with environmental risk mitigation from the field development with none. The eco-efficiency of each pound of investment to mitigate adverse environmental risk can then be calculated. This is the amount of environmental benefit generated by a pound spent. The information supplied by the analysis can be used to indicate to the operator what the most environmentally and economically effective level of expenditure will be for a proposed field development.

Further qualitative environmental risk information is required in addition to the estimated level of benefit to ensure that the assessment is holistic. Those environmental aspects that cannot be quantified using damage costs are identified and prioritised on the basis of their risk indices (see section 5.4.3.7.). Thus the choice of mitigation design for a field will require the consideration of both qualitative and quantitative information. This is illustrated in Table 5.16.

Field Mitigation Design	***Total Cost (£m)***	***Environmental Benefit (£m)***	***Benefit/Cost***	***Unquantifiable Environmental Aspects***
▪ System 1	22	10.5	0.47	**1. Maximum Tolerable Region** ▪ Long-term Seabed Wastes **2. Maximum Just About Tolerable Region** ▪ Visual Eyesore ▪ Disturbance to Local Population **3. Acceptable without Action** ▪ Heated Water Discharges
▪ System 2	20	12.0	0.60	

Table 5.16. Environmental Mitigation Risk System

HEA uses environmental benefit as a performance indicator (along with the unquantified information) to identify an environmental risk mitigation system for a field development programme that is eco-efficient. The benefit/cost ratio, detailed above, is the indicator that will identify the most eco-efficient and cost effective environmental risk mitigation system, and may equal to, greater or less than 1.

5.5.2 Phase I - sensitivity analysis

During the HEA process, the prioritised environmental aspects, the environmental damage they cause, and consequential expenditure to mitigate may be mapped out. How these relate to the design and management of the proposed field development may be evaluated by a sensitivity analysis. A sensitivity analysis may be performed using a

Monte Carlo simulation. The relative importance of an environmental aspect/mitigation technique can be evaluated by calculating the correlation coefficient of each input variable with the outcome. The higher the coefficient, the stronger the dependence between the input variable and the outcome. It identifies those environmental aspects to which the total environmental damage cost is most sensitive. It will also identify those quantities or occurrence of environmental aspects, which result in only small changes in total environmental damage cost. The results of the sensitivity analysis can be used to identify where investment into mitigating adverse environmental risk will reap the greatest environmental benefit, and those areas where it will not. It will also highlight those particular techniques that are reducing risk in one area but transferring it to another. This will allow the identification of areas where higher levels of environmental performance may be achieved.

5.5.3 Phase J – assessment of the impact of the environmental risk mitigation cost on the project's economic performance indicators such as: net present value and internal rate of return

The cost of the chosen Environmental Mitigation Risk System is internalised into the cash flows of the *field development programme.* The Cash Flow method is used to calculate the Net Present Value (NPV) and Internal Rate of Return (IRR) of the asset which has been designed under HEA to produce energy in accordance to the three principles of Sustainable Development: economic prosperity, environmental quality and social justice. By incurring the cost of minimising environmental risk to a level that is acceptable (see Section 5.4.3.7) a price is generated establishing a market-based cost value for an asset (environmental quality) that in the past was considered "free". Environmental damage costs are not included in the NPV and IRR calculations because they are non-market values.

The impact of the cost incurred by reducing the environmental risk posed on the field development is calculated using equation (10).

$$NPV = \sum_{t=1}^{n} \frac{R_t - (C_t + E_t)}{(1+i)^t} > 0 \qquad \text{(where } t = 1,2....\text{n)} \qquad (10)$$

where R = revenue (£)

C = capex and opex of the field development (£)

E = environmental expenditure (£)

i = Discount Rate

In summation the cost data, the environmental benefit data and the unquantifiable environmental risk data generated by HEA represents the total environmental risk posed by the *field development programme* with a chosen level of environmental risk mitigation. The data generated from the HEA process can be combined with environmental performance data from other existing or proposed future developments to provide strategic information on the total environmental performance of the company.

5.6 APPLICATION

The HEA process is implemented on a 'real' case study field development programme using simple environmental modelling instead of complex software to assess the scale and risk of environmental impact for a Field Development. The results of this assessment are presented in Chapter 6.

6 Results

6.1. CASE STUDY FIELD X DEVELOPMENT

This chapter applies the Holistic Environmental Assessment (HEA) process to a 'real' case study Field Development Programme, Field X. The proposed Field X particulars are presented in 6.1.1. Some of these will change following decisions made after undertaking an HEA. For example, at the moment the proposed fate of the decommissioned facility in the future is sea-based however this, in accordance to regulation, will have to become land-based.

6.1.1 Field X Particulars

Phase	Parameter	Value
1. Reservoir	Location	X Field, Quadrant 22/12 UK Central North Sea Basin
	Existing Reservoir Data Sources	Two 2D surveys (1970/1975); an exploration well in 1975; 5 appraisal wells between 1977-1979
	Reservoir Characteristics	▪ High permeability, massive shallow marine sandstones from the Upper Jurassic comprise the main reservoir unit. ▪ High permeability, turbidite sandstone also from the Upper Jurassic appears to be located within the overlying cap rock on the southwestern flank of the field ▪ Uncertainty over the extent of faulting requires a 3D seismic survey
	Probable Oil in Place	770 MMSTB
	Probable Economically Recoverable Reserves	462 MMSTB of oil and 1556 BSCF of gas
	Recovery	Water injection
	API	40°
	Estimated Field Life	12 years
2. Reconnaissance	Location	X Field, UKCS North Sea
	Depth of Water at Field	120m
	Survey Type	3D: 10 streamers 2,400 m long
	Survey Area	100 km^2
	Survey Length	2 months
	Airgun Array Noise Output	222 dB rel 1µPa @ 1m – Shot at 25 m intervals
	No of people at sea	35
3. Exploration & Appraisal Drilling	Exploration Wells	0
	Appraisal Wells	1 – Eastern Flank of Field Structure
	Drilling Facility	Semi-submersible drilling rig
4. Production	Production Wells	9
	Injector Wells	14
	Drilling Facility	2 Semi-submersible drilling rigs (Appraisal and Production wells drilled by same facility)
	Production Facilities	▪ Main platform subsea driling template will be installed 2 years prior to the installation of the production platform. ▪ Subsea template for injection wells will be installed 1 month after the production template. ▪ Platform will provide required production, drilling, quarters and utilities functions for the field. ▪ Plant includes: twin train horizontal two stage separator, water injection pumps and filters, produced water treatment equipment; CO_2 and H_2S removal equipment, gas compressors and electrical power generation equipment.
	Peak Production of Oil	275,000STB/day
	Peak Production of Gas	165 MMSCF/day

5. Transportation	Mode of Transport for Oil	45 km long 24" tie-in pipeline to existing Forties pipeline (capacity: 400,000STB/day)
	Mode of Transport for Gas	60 km long 18" tie-in pipeline to the CATS via Everest platform
	Forties Pipeline	164 km, 36" pipeline to Cruden Bay via the Charlie Platform (capacity: 1millionSTB/day)
	Cruden Bay Onshore Pipeline	209 km, 12" pipeline to refinery facilities at Grangemouth (capacity 1.15millionSTB/day)
	Everest Pipeline	408km, 36" pipeline – the Central Area Transmission System (capacity: 2000MMSCF/day) to Teeside
6. Decommissioning	Fixed Platform Material	Steel
	Topsides	21,000 tonnes
	Jacket	16,000 tonnes
	Disposal	Sea-based

6.2. STAGE 1 - LIFE CYCLE ENVIRONMENTAL MITIGATION ANALYSIS

1. Life cycle analysis of the environmental aspects posed by oilfield development
2. Identification of the legislation and economic instruments that govern each environmental aspect
3. Identification of the best available environmental risk mitigation technologies and techniques, and their costs

6.2.1 Reservoir Management

6.2.1.1 Formation Damage

ENVIRONMENTAL ASPECT
Produced water injected into a reservoir may cause potential formation damage. Oil droplets form a thin internal filter cake in the rock that reduces flow, and an external filter cake on the fracture face. The overall impact of injecting hot, oily contaminated effluent into the reservoir is little understood and is undergoing study. Other formation damage problems include emulsion and scaling particulate blocking, and a loss of fracture conformance control. These problems may affect the characteristics of a reservoir and hence of producing wells in the area. There is also a minor risk of fracturing assisting in the vertical migration of produced water to the seabed.

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislation over Formation Damage
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)

MITIGATION MEASURES
An area of the Treatment of Water Offshore programme, a collaborative academic and industry research initiative, is assessing the effects of oily water flowing along a fracture and through fracture faces and identifying the potential formation damage consequences to assist in the development of guidelines on the specification of produced water quality for injection. To reduce formation damage it has been proposed to mix produced water with sea water before injection. This is under field trial by Aker Engineering AS.

Skim tanks, hydrocyclones, floatation equipment, downhole separators filters and pumps are some of the plant that may be used to treat produced water. A solid state laser can identify the amount of solids in water. This identifies any solid with a diameter of 1μm or more. It may be used to assess whether solids removal equipment such as filters and hydrocyclones are effective, to minimise formation damage prior to produced water re-injection. For a more thorough detailing of produced water treatment see Section 6.2.6.6. There is a potential for making cost, space and weight savings through the optimisation of water treatment facilities and a PWRI system during the life of a field (Hjelmås et al., 1996). Data on the capital and operational costs are necessary to establish an economic basis for the injection water quality.

6.2.2 Seismic Surveying - routine operations

6.2.2.1 Transportation of vessel to site and along transects

ENVIRONMENTAL ASPECT
Ballasting, or cleaning of, and discharge of dirty ballast or cleaning water from bunkerfuel tanks, disposal of oil residues, overboard discharge of oily water that has accumulated in machinery spaces – including pump rooms, whilst in port and the routine discharge at sea of oily bilge water; Exhaust emissions to air; Potential interaction with other users of the sea. (Seismic vessels range from 400-3,500 GRT, Typical range between 1,000-1,500 GRT).

UK ENVIRONMENTAL REGULATORY CONTROL
- Petroleum Operations Notice 14
- Pending international legislation controlling the introduction of non-native species into UK waters from ballast water (a proposed Annex VII to MARPOL), there are IMO Guidelines for the control and management of ship's ballast water to minimise the transfer of harmful aquatic organisms and pathogens
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
    - Prohibition of oily discharges inside the 3nm limit
    - Ships delivered before 6/7/93 – discharges are prohibited unless vessel is on a voyage, is 12 nm from land and the oil content is less than 100ppm
    - Modern ships – discharges are prohibited unless vessel is under voyage and the oil content is less than 15ppm
    - Vessels greater than 400 gross registered tonnes must have an oil/water separator, oil sludge tanks, a Shipboard Oil Pollution Emergency Plan, a UK Oil Pollution Prevention Certificate (UKOPP) and an Oil Record book
- Annex VI of MARPOL 73/78 Regulations for the Prevention of Air Pollution from Ships

MITIGATION MEASURES
Under the Merchant Shipping (Prevention of Oil Pollution) Regulations 1996, the Maritime and Coastguard Agency has issued instructions to marine surveyors to ensure that adequate pollution prevention equipment is fitted to all ships. This includes a survey of a ship's structure. They detail the conditions required for the issuing of oil pollution prevention certificate (The Maritime & Coastguard Agency, 1999). To avoid the contamination of ballast water with hydrocarbons a Segregated Ballast Tank System is fitted that completely separated ballast water from the cargo oil and fuel oil systems. Since the North West European Waters were classified as a 'Special Area', the UK has confirmed that is has adequate facilities for the reception of dirty ballast and tank washing water from vessels operating through out the area. (Such facilities are required under the Prevention of Oil Pollution (Reception Facilities) Order 1994 & The Merchant Shipping and Maritime Security Act 1997). Other equipment includes oil-water separating equipment; oil filtering equipment; Oil Discharge Monitoring & Control System (ODMC) including 15 ppm oil in water engine bilge alarm; and slop tanks (For fuel tank washings, oily sludge, and dirty ballast water).

Diesel engines are highly efficient combustion engines and do not produce a significant amount of evaporative emissions. The fuel is completely converted to CO_2 and H_2O, CO and HCs are quite low. Nitrogen oxides and particulates are a problem for diesel. Most of the sulphur in diesel fuel is converted into SO_2, and emitted as gas (Hatamian, 1997). See 6.2.4.2.

Operators must advise the DTI and any other parties specified in the licence conditions, of proposed Geophysical Surveys 28 days before a survey is commenced. The consultation requirements are detailed in PON 14. Consultation and notification of seismic activity prevent or minimise any interaction with seismic activities. An operator is advised, by Government Fisheries Agencies and the UK Offshore Operators Association, to consult fishermen with traditional fishing grounds in a proposed seismic area. It is recommended by such agencies that the interaction with static fishing be avoided.

6.2.2.2 Mobilisation of airgun array and streamers – 'Launch and Recovery'

ENVIRONMENTAL ASPECT
Power generation atmospheric emissions

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislative controls

MITIGATION MEASURES
Cutting down on 'launch & recovery' could be achieved by making the assembly more reliable, efficiently designed for towing and planning for equipment maintenance. Fewer 'launch & recovery' operations would reduce atmospheric emissions.

6.2.2.3 Firing airgun array

ENVIRONMENTAL ASPECT
Propagation of high energy, low and high frequency sound every several seconds; Atmospheric emissions from power generation

UK ENVIRONMENTAL REGULATORY CONTROL
- Petroleum Operations Notices 14
- Guidelines for the Minimisation of Acoustic Disturbance to Small Cetaceans

- Annex VI of MARPOL 73/78 Regulations for the Prevention of Air Pollution from Ships

MITIGATION MEASURES
30 minutes before firing airgun array it is recommended to see or hear if there are any marine mammals within 500 metres of the facility. If they are any it is recommended that firing should commence at least 20minutes after last recorded departure from 500 metre zone. At this stage, it is recommended that firing should begin slowly from a low energy out-put (starting with the smallest air-gun and slowly adding in others) increasing to high over at least 20 minutes. Such a soft start is recommended even if no marine mammals have been recorded. It is also recommended that seismologists use the lowest practicable power levels necessary to collect their data.

The Joint Nature Conservation Committee recommends that a report detailing marine mammals sighted, the methods used to detect them, problems encountered and nature of air-gun discharge should be compiled and sent to them to improve future mitigation

British fishery sensitivity maps have been published by the UK Fisheries Agencies with support from the UK Offshore Operators Association. These maps detail species spawning and nursery areas and recommend exclusion windows to minimise seismic disturbance to species during these phases of their life-cycle. Operators may use these maps to ensure their seismic operations do not have an adverse environmental impact on commercial species of fish.

Under UK good industry practice, a Fisheries liaison officer and a whale and dolphin observer are employed to prevent any adverse environmental impacts.

6.2.2.4 Towing of equipment

ENVIRONMENTAL ASPECT
Presence of equipment, temporary exclusion zone; Cable either floating or trawled along the seabed; Generation of low frequency noise

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
The towing of equipment is an essential part of the geophysical survey offshore. How the equipment is towed determines in certain circumstances whether there will be an environmental impact or not. A pre-area survey for any environmental sensitivities (usually by consultation with experts) should ensure that an appropriate method of towing is adopted. This is particularly relevant in the case of offshore reefs, and animal breeding and spawning grounds.

6.2.2.5 Utilities and logistics

ENVIRONMENTAL ASPECT
Helicopter generated noise, fuel re-loading, disposal of helifuel samples, exhaust emissions to air, chemical discharges from washing, disposal of sewage, canteen and medical wastes

In a 1995 survey of seismic vessels and their wastes, carried out by Environment and Resource Technology, the following was recorded:

- Maximum number of people at Sea: 50 (ranging from 30-40)
- Duration at sea: Maximum 35 days, minimum 1-2 days
- Deck and domestic waste: 1-2kg/day/person
- Special waste: <1 tonne/year
- Scrap metal: <5 tonnes a year not including damaged cable
- Black water/grey water: 200-250 dm^3/day/person

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) Regulations 1996
- Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1998
- Annex IV of MARPOL 73/78
- Environmental Protection Act 1990; Environmental Protection (Duty of Care) Regulations 1991; Environment Act 1995; Special Waste Regulations 1996; Waste Management Regulations 1996; Controlled Waste Regulations 1992

MITIGATION MEASURES
Garbage disposal at sea is prohibited and consequently is segregated on board before disposal at a reception facility from hence the waste is either salvaged, incinerated or treated and landfilled. Special waste (as defined under the Special Waste Regulations 1996) is taken ashore for licensed treatment and disposal. Galley waste is macerated prior to discharge and past through a 25 mm mesh. At the time of writing, Annex IV of MARPOL had not been enacted into UK law and therefore sewage may be discharged offshore. Helifuel samples are disposed of with other oily wastes into a slops tank.

6.2.3 Seismic Surveying - accidents

6.2.3.1 Spillage and VOC emissions during re-fueling, seismic streamer rupture releasing kerosene to the sea

ENVIRONMENTAL ASPECT
Release of buoyancy control fluid or oil to the sea

UK ENVIRONMENTAL REGULATORY CONTROL

- Seismic surveying does not require the preparation of an oil spill contingency plan
- Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulations 1997
- Merchant Shipping (Reporting Requirements for Ships Carrying Dangerous or Polluting Goods) Regulations 1995
- The Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- FEPA, 1985 Prevention of Dumping at Sea

MITIGATION MEASURES
The seismic vessel burns 30 tonnes of fuel on average each day. Amount of fuel on board in bunker is approximately between 450 tonnes to 500 tonnes. A seismic survey make take anywhere between 1 month and 7 months, 24 hours a day, as a result a tanker is required to refuel the seismic vessel approximately every two weeks.

There are several emissions control methods that are available for truck loading which could be applied to marine loading. These can be characterised as recovery systems or combustion systems, or a combination of the two: compression-absorption; compression-cooling; cryogenic refrigeration; adsorption systems (adsorption-absorption, or absorption-adsorption-absorption); vapour combustor systems (open or enclosed flare, or incinerator); vessel mounted systems (Hill, 1990).

Vos Process Systems (Netherlands) market a vapour recovery system that utilises an American technique based on the principle of adsorption on to active carbon. It is designed to prevent the escape of VOCs into the atmosphere.

6.2.3.2 Mishandling of materials such as plastic sheeting, bags, containers, oil drums, lengths of wire and heavy equipment

ENVIRONMENTAL ASPECT
Persistent waste released to sea

UK ENVIRONMENTAL REGULATORY CONTROL

- Petroleum Operations Notice 2 - "Special precautions should be taken to prevent the loss of such materials and articles mentioned above. In the event of the loss of such materials and articles overboard or when being towed, every reasonable attempt should be made to recover them".
- Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1998
- Food and Environmental Protection Act 1995

MITIGATION MEASURES
Development of a waste management plan; If a vessel has a plan in place already HSE training and management can improve handling practices on decks and thereby prevent the accidental dropping of objects overboard. It would be an infringement of the Food and Environmental Protection Act to leave dropped objects on the seabed. There is no facility for collecting waste once accidentally dropped overboard for safety reasons.

6.2.4 *Drilling - routine*

6.2.4.1 *Rig fabrication*

ENVIRONMENTAL ASPECT
Dredging and filling of coastal habitats

UK ENVIRONMENTAL REGULATORY CONTROL
- Coast Protection Act 1949

MITIGATION MEASURES
Environmental Assessment process resulting in an Environmental Statement being prepared under the Harbour Works (Assessment of Environmental Effects) (No.2.) Regulations 1989 to obtain consent from the Minister of Transport. (These regulations do not cover Northern Ireland) This ensures safe passage of vessels in the area and a restriction of works detrimental to navigation. The facility construction company undertakes the cost of preparing an environmental statement and not the drilling company. Thus, there are no direct environmental expenditure costs associated with this operation.

6.2.4.2 *Rig/drill ship/vessels transport to site*

ENVIRONMENTAL ASPECT
Exhaust emissions (CO_2, NO_2, SO_2, and particulates); Potential interaction with other users of the sea

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78

MITIGATION MEASURES
Diesel engines are highly efficient combustion engines and do not produce a significant amount of evaporative emissions. The fuel is completely converted to CO_2 and H_2O, CO and HCs are quite low. Nitrogen oxides and particulates are a problem for diesel. Most of the sulphur in diesel fuel is converted into SO_2, and emitted as gas (Hatamian, 1997). Although a discharge of exhaust emissions will occur it is considered by environmental experts working for the industry that the quantity discharged is an immeasurably small-scale contributor to global warming and acid rain, and deteriorates local air quality for a short period only. In the past emissions were managed primarily by diesel engine servicing.

Vessels of 400 GRT and above, and platforms and installations under voyage will require an Air Pollution Prevention Certificate when the requirements of Annex VI of MARPOL are enacted into UK law. This certificate ensures that such facilities have air pollution prevention equipment and measures. Any deliberate emission of ozone-depleting substances will be prohibited. New equipment that contain ozone-depleting substances will be prohibited, except in those containing hydrofluorocarbons (HCFCs) that are permitted until 1st January 2020. The use of diesel engines is prohibited except where the emission of nitrogen oxides (Calculated as the total weighted emission of NO2) from the engine is within the following limits:

- *17 g/kWh when n is less than 130 rpm*
- *45.0 x $n^{-0.2}$ g/kWh where n is 130 or more, but less than 2000 rpm*
- *9.8g/kWh when n is 2000 rpm or more*

(where n = rated engine speed, crank shaft revolutions per minute).

The operation of a diesel engine whose emission thresholds are greater than the above is permitted if these thresholds are achieved using an exhaust gas cleaning system or some other environmental technology. The sulphur content of any fuel used on board ships is limited to 4.5% m/m. In designated SOx emission control areas this maybe limited to 1.5% m/m, or with approved exhaust gas cleaning system, or some other environmental technology, to 6.0g SOx/kWh from auxillary and main propulsion engines. To reduce VOC emissions particular ports and terminals will be designated by the International Maritime Organisation to have vapour emission control systems for incoming cargo vessels. Vessels will be required to have vapour emission control systems. Shipboard incineration will only be permitted when using an approved shipboard incinerator. MARPOL Annex, I, II, II cargo residues and related contaminated packaging materials, polychlorinated biphenyls, garbage containing more than traces of heavy metals; refined petroleum products containing hydrocarbons and polyvinyl chlorides (except where approved by the IMO) will be prohibited. Shipboard incineration of sewage sludge and sludge oil is permitted except in ports, harbours or estuaries (IMO, 1998).

Operators issue notification of the movement of an offshore installation, check shipping traffic activity and identify safe havens in case of bad weather conditions. This is primarily directed to other oil and gas industry activity and to fishermen. An operator may appoint a fisheries liaison officer to undertake consultation with fishermen.

6.2.4.3 *Hook-up and commissioning*

ENVIRONMENTAL ASPECT
Atmospheric Emissions from generator used to power crane; Statutory 500-m exclusion zone (0.8 km^2); Potential interaction with other users of the sea; Presence of a new marine substrate and artificial offshore island

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78
- Coast Protection Act 1949
- Continental Shelf Act 1964
- Notices to Mariners (M Notices) or navigational warning
- Petroleum Operations Notice 10
- DETR Merchant Shipping Regulations
- Offshore Petroleum Production and Pipe-Lines (Assessment of Environmental Effects) Regulations 1999

MITIGATION MEASURES
Exhaust emissions from operation of crane are inevitable. Zero emissions are impossible even with electrical power or the use of clean fuels such as hydrogen. Equipment with zero emissions produce a pollution displacement effect i.e. from the equipment to fixed power generating plants or industrial plants. Local pollutants will be reduced, but life-cycle analysis will show that resource use or global impacts will remain. Although a discharge of exhaust emissions will occur it is considered by environmental experts working for the industry that the quantity discharged is an immeasurably small-scale contributor to global warming and acid rain, and deteriorates local air quality for a short period only. See 6.2.4.2.

Construction Notification is submitted to the Health and Safety Executive 28 days prior to activity. Buoys and navigation charts mark the 500m-exclusion zone (0.8 km^2) and facility. By law, an operator consults and notifies, during the preparation of an environmental statement, fishermen and other interested parties, including Ministry of Defence, The Archaeological Diving Unit (St. Andrews), British Telecommunications and Nature Conservation Organisations. A Fishing Liaison Officer may be appointed for consultation with fishermen. See 6.2.4.2.

6.2.4.4 Anchoring and ballasting the facility

ENVIRONMENTAL ASPECT
Physical disturbance to the seabed from anchoring, increase in localised turbidity, re-suspension of sediment, discharge of ballast water

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislation controlling the introduction of non-native species into UK waters
- IMO Guidelines for the control and management of ship's ballast water to minimise the transfer of harmful aquatic organisms and pathogens
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Petroleum Production (Seaward Areas) Regulations 1988

MITIGATION MEASURES
Drilling facilities tend to be constructed or are under operation in the North East Atlantic and thus the risk of introducing non-native species should be zero.

Depending on type of platform being deployed, anchor studies may be undertaken to determine an appropriate anchoring system suitable for seabed soils. This is used to prepare anchor-handling procedures. Safe distances from existing pipelines and other pipelines are established. Digital Global Positioning System may be used to monitor facilities position during anchoring operations. By law, an operator consults and notifies, during the preparation of an environmental statement, fishermen and other interested parties, including Ministry of Defence, The Archaeological Diving Unit (St. Andrews), British Telecommunications and Nature Conservation Organisations. This ensures that there is no interference with ordnance dumpsites, wreck sites, power cables, pipeline routes and other wells.

6.2.4.5 Drilling

ENVIRONMENTAL ASPECT
Marine discharges and atmospheric emissions, oil and chemical additives, cuttings, weighting material, heavy metals, solvents and lubricants. Generation of low frequency noise

UK ENVIRONMENTAL REGULATORY CONTROL
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Food and Environment Protection Act 1985 - Deposits in the Sea (Exemptions) Order 1985
- Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1996
- The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997
- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)
- Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 1999
- Atmospheric emissions are monitored and recorded in database on emissions into the atmosphere which is managed by UKOOA (Environmental Emission Monitoring System)
- No legislative controls over produced noise in water or air
- No Statutory CO_2 Emissions Trading System

MITIGATION MEASURES
Mud and Cuttings
Since discharging 1% oil on cuttings is not currently feasible, the majority of oil contaminated cuttings have been disposed of either on shore or by high pressure injection into formations below the sea bed since 1 January 1997. OBMs are contained, transported ashore

and disposed of. Industry is undertaking research into alternative methods of disposal including: cuttings re-injection; landfill disposal after chemical or thermal treatment; and biodegradation by land farming, see 6.2.4.16. Total containment technology was tried and tested with success by Shell Expro in 1994 for the Leman reservoir (McCoy, 1997). In 1997 Amoco drilled using a Total Containment System in the environmentally sensitive Haltenbanken area off Norway (Hanni 1998). Technology is developing to process and ship higher volumes of cuttings to shore including: larger storage tanks on facilities, workboats and quays; improved pumps and process equipment; and specific vehicles to transport cuttings to treatment plants. Chemical discharges are voluntarily monitored by industry and quarterly accounts are sent to the DTI, and recorded in their SCOPEC database.

***SBMs** are in the process of being phased out. A SBM is not a chemically uniform product. They can be re-cycled limiting the amount discharged from the facility. They may either rented or sold and then repurchased by the supplier*

***WBMs** are used in 80% of drilling operations world-wide. They are 70% water and discharged onsite into the sea. HOCNF encourages the use of chemicals in any drilling fluid that have a low toxicity to marine fauna. For this reason WBMs are used and contain chemicals that are approved by the SERAD or MAFF, and the DTI. A greater volume of WBM is required than OBM to drill therefore increasing the quantity discharged.*

***LTOBMs** are developed to maintain the drilling characteristics of an OBM whilst also having the low environmental impact of a water-based mud. Oil based mud formulated with mineral oil (<0.1% aromatics) and palm tree oil (without aromatics) have been developed in Venezuela to overcome the HSE risks associated with diesel-based drilling fluids. Such oil that has contaminated cuttings has been demonstrated in case studies to readily biodegrade (Sáchez et al., 1999). Research is being conducted into using vegetable oils, such as rape seed oil, for offshore drilling operations. It is less toxic and rapidly biodegradable by comparison to mineral oils, which may take up to twenty years to degrade. The concern with this technology is if successful whether it will encourage the cultivation of genetically modified rape seed, the use of which appears to be against public interest and, following an environmental assessment by the Environment Agency, poses a threat to Britain's wildlife.*

Technology is available to clean-up existing mud piles, which can affect the structural integrity of an installation and potentially interfere with trawlers after a platform has been decommissioned.

Drainage during drilling

Lube/fuel oil tanks and machinery spaces will be fitted with bunding to collect spilllages of oil or oily waste. These bunded areas have drains which connect to the bilge storage tank. Oily wastes may be transferred from the bilge storage tanks to waste oil storage tank for shipment ashore, treatment and disposal. All drains from the rig floor can be directed into the bilge storage tank.

Combustion

Atmospheric emissions are monitored and recorded in database on emissions into the atmosphere which is managed by UKOOA. Main source of CO_2 is the combustion of fuel gas for power generation processes. Optimisation of energy usage and increased combustion efficiency would reduce CO_2. However there are other methods available.

The cleaning up of the atmosphere from hydrocarbons is still under research and development. The use of fossil fuels and the subsequent release of large amounts of carbon into the atmosphere have focused attention in this area. Anthropogenic releases of hydrocarbons are considered by the National Oceanic and Atmospheric Administration and the Intergovernmental Panel on Climate Change to cause an imbalance in the planet's carbon cycle and enhance global warming. To control this, research and work has been undertaken to begin to increase the amount of atmospheric carbon being fixed by the process of photosynthesis. Most measures offset the release of carbon back into the atmosphere:

1. *USA and UK scientists undertook the IronEx experiment to fertilise the oceans with iron under the hypothesis that adding iron would cause a planktonic bloom and 'pull' carbon out of the air. The experiment worked and mimicked the theory that during the last ice age, iron was responsible for keeping atmospheric levels of carbon dioxide (CO_2) low, thereby keeping the planet cool. The plankton emit dimethyl sulphide, a gas that oxidises in the atmosphere to form sulphate particles. These particles directly shield the Earth's surface from solar heat and 'seed' the formation of clouds (Pearce, 1996);*
2. *Japan's National Institute of Biological & Human Technology in Tsukuba Science City and the Research Institute of Innovative Technology for the Earth in Kyoto state that they can use cyanobacteria (Synechococcus sp.) to soak up CO_2 from the air and produce polyhydroxybutric acid (PHB). Joining PHB in a co-polymer with a hydroxyvalerate produces a biodegradable plastic. At the time of writing, it was stated that the technology hadn't reached commercialisation (Hadfield, 1997);*
3. *Trees and other plants take up and store CO_2 so an alternative way to reduce global warming is to plant new forests. The forests must then be conserved to prevent the CO_2 being released back to the atmosphere. The most common form of project for CO_2 absorption is likely to be reforestation of derelict or degraded lands, which are of marginal agricultural potential or high conservation value. The new forests will restore, as far as possible, the natural ecology of the area; they will not be plantations. In is the efficiency of regeneration in the forest that will determine if it is an effective long-term store of carbon. Once the forest has reached its climax, it will not be a sink of carbon as due to the balance of photosynthesis and respiration in a food web, the stable ecosystem is not a net absorber of CO_2. This process brings with it many other environmental benefits such as conservation of soil, water supplies and habitats for local wildlife. However the land that the forests take up is no longer available for other uses – forever. To put this into context; if the UK were to offset only one year of its CO2 emissions by planting forests it would have to set aside an area equivalent to Devon and Cornwall.*
4. *Projects to develop renewable resources of energy are measures that serve to reduce the global warming risks posed by the burning of fossil fuels and are recognised by the Kyoto Protocol. These can offset the total environmental change that a company may be producing.*
5. *Large amounts of CO_2 and other unwanted greenhouse gases from offshore oil and gas fields can be disposed of into underground aquifers (Baklid A, 1996). Injection of CO_2 far offshore practically eliminates the risk of resurfacing of the gas in populated areas. The re-capturing of CO_2 and injecting into the substrata offers an opportunity for carbon management. Re-capturing research is detailed above and it is possible that CO_2 may be captured and maintained in a biological medium before re-injection and storage underground.*
6. *Aquifer disposal*
7. *CO_2 injection in depleted reservoirs*
8. *CO_2 injection in improved oil recovery processes*
9. *CO_2 sequestering in the form of gas hydrates*
10. *CO_2 sequestering by bacteria and algae*

11. CO_2 for enhanced coal-bed methane
12. Direct Ocean-based disposal

Noise
UK operators do not implement environmental control technologies to ensure that the noise offshore from drilling does not disturb marine mammals, seabirds or fish. However, noise restrictions are imposed, Elf Petroland B. V.'s Zuidwal production platform in the Waddenzee of Holland was developed with minimum noise levels and helicopter transportation was permitted only in an emergency (Moritis, 1990).

6.2.4.6 Cementing casing

ENVIRONMENTAL ASPECT
Atmospheric emissions during mixing; Marine discharge of cement and chemicals

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
For mitigation against degrading local air quality see 6.2.4.7. The cement used is designed to set as quickly as possibly to ensure that the casing adheres strongly to the borehole. For this reason it is good practice to ensure that the amount of excess cement is minimised. This is achieved by calculation and by using a fluorescent dye that helps to identify cement returns.

6.2.4.7 Mud separation and mixing - drilling module ventilation

ENVIRONMENTAL ASPECT
Fugitive vapour losses to air from oil-based and water-based muds at 0.25-0.5m^3/hr. Losses vary on the mud and cement system design. For a well using OBMs with say 150 circulating hours, 50m^3 of oil loss would not be abnormal ($\pm$45 tonnes).

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls
(Recommendations on reducing the impact of VOCs in Montreal Protocol.)

MITIGATION MEASURES
Apart from offshore loading, vent and fugitive gases are the main source of VOC emissions. Mud mixing and storage areas tend to be separate from the mud/solids separation system. Vapour losses from separation systems may be reduced by degassers (integrated extract fans with built in filters and coolers. Mixing hoppers and tanks may or may not be vented and filtered. In some cases tanks will be vented and overall module ventilation will also be provided. Due the limited time spent mixing, losses are small and dependent on system design. However they are of significant interest from safety and occupational hygiene interest (Institute of Offshore Engineering, 1997). To reduce ozone pollution, controls are better directed at VOCs with the highest Photochemical Ozone Creation Potentials (POCPs). Ventilation systems include: natural; point extraction using local fans, ducted vents and mixture of the aforementioned (Institute of Offshore Engineering, 1997).

6.2.4.8 Bulk material handling (barite, cement, bentonite, whole mud, base oils or other base fluids)

ENVIRONMENTAL ASPECT
Losses to sea due to on-platform transfer and loading, or accidental hose failure; Atmospheric emissions during mixing.

UK ENVIRONMENTAL REGULATORY CONTROL
- Food and Environment Protection Act 1985

MITIGATION MEASURES
Fluid Transfer Permits ensure safe handling. The careful operation of tanks and valves and flotation collars attached to transfer hoses will ensure low environmental risk.

Using storage containers that are readily re-sealable may reduce venting of dry materials. Solid materials are conveyed from supply vessel to platform by pneumatic pumping (air fluidisation). Reception tanks are therefore vented and generally include some form of filtration device. On platform transfer uses using the same system however, conveyor and gravity feed systems are beginning to be used. Due to the limited on-platform transfer rates losses are generally negligible. However, during loading losses can be significant if an ineffective vent/filter system exists. Studies by the Institute of Offshore Engineering have recorded that 30% losses would not be uncommon for a 'poor system', with less than 5% for a good system (Institute of Offshore Engineering, 1997).

6.2.4.9 Chemical handling

ENVIRONMENTAL ASPECT
On platform handling, disposal of residual drilling chemicals in containers onshore

UK ENVIRONMENTAL REGULATORY CONTROL
- Food and Environment Protection Act 1985

MITIGATION MEASURES
Drilling chemicals are contained in paper sacks, drums or 'tote' tanks. On platform losses should be minimal as long as careful handling procedures are used. Studies conducted by the Institute of Offshore Engineering highlighted that significant losses of chemicals are possible with trash and returned containers. For example up to 0.25kg from 15kg sacks may still be found in the cut sack in a trash container and 10% of drummed chemicals (200 dm^3 drums) may be remaining in the drum returned to shore. Any environmental impact is thus transferred from the offshore facility to the onshore disposal system (Institute of Offshore Engineering, 1997).

6.2.4.10 Wireline and well treatment (workovers)

ENVIRONMENTAL ASPECT
Venting of well pressure will result in the emission of gas to air and/or discharge of oil to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Food and Environment Protection Act 1985

MITIGATION MEASURES
Wells are worked over to increase production, reduce operating cost or reinstate their technical integrity (Jahn et al.,1998). Vents may be to the atmosphere via bleed line to flare or to a closed drain system or to an open 'hazardous' drain. Good practice will ensure that the fates of vented products have minimal environmental impact. Pressure testing equipment for integrity prior to use highlights any potential environmental risks.

Measurement while drilling (MWD) technology eliminates the need to stop drilling and collect 'open hole' log data. Thus wireline logging is no longer necessary and the additional costs of 'open hole time' and the risks to the borehole are eliminated. There are no direct environmental expenditure costs associated with this operation.

6.2.4.11 Well clean-up and Testing (Completion)

ENVIRONMENTAL ASPECT
Flaring of oil, gas and/or condensate, unburnt hydrocarbons fall to the sea; Atmospheric emission and marine discharge of oil, dioxins, polycyclic aromatic hydrocarbons, and heavy metals.

UK ENVIRONMENTAL REGULATORY CONTROL
- Petroleum Production (Seaward Areas) Regulations 1988
- Atmospheric emissions from offshore installations arising from flaring and venting are not required by law to be monitored
- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- No Statutory CO_2 Emissions Trading System

MITIGATION MEASURES
A public demand for near-zero emissions to the sea and atmosphere could only be achieved by not flaring the oil and collecting it in a tank for subsequent shipping to a process facility. Under certain circumstances such a facility will be remote and a comparative assessment would need to be undertaken to address the environmental balance of the options. Exploratory drilling units are not always equipped with adequate processing facilities to stabilise, collect and store petroleum products, and they are flared.

Whether the well test is an extended well test (EWT) or a drillstem well test determines the duration of the test and hence the quantity of emission. An EWT may take several weeks or months and a drillstem test several days. In such cases where an EWT is undertaken, any oil or gas produced may be transported ashore if the relevant infrastructure is present, to minimise the environmental impact. Gas can only be transported ashore by pipeline. The lying of a pipeline to collect gas and prevent flaring from a well test is uneconomical. Tankers may be used to collect oil from such tests e.g. Statoil have developed the Crystal Sea a specialised clean-up and well testing vessel that can collect oil that would otherwise need to be flared due to a lack of available infrastructure. This cuts emissions to air and hydrocarbon spillage to sea and provides financial gain to the operator (Statoil, 1998).

The global warming potential of ratio of CH_4 to CO_2 is 21:1 which makes the burning CH_4 as a flare, a more suitable option for any surplus gas problem. However the challenge is to eliminate any flaring (or venting) which may be achieved gas injection for improved oil recovery, liquefaction of the gas for LPG exports or storing surplus gas in depleted reservoirs

Combustion efficiency determines performance. Poor combustion will result in liquid drop out and part pyrolised materials occurring. This is of concern when the burner unit is used for hydrocarbon-contaminated solids and chemicals including *spent acids. Unburnt hydrocarbons that fall to the sea during flaring, are treated as an oil spill and cleaned up using processes detailed in an operator's oil spill contingency plan. See 6.2.5.3. Thus, to minimise any environmental liability there is a need for efficient combustion and additional gas or diesel may be required to achieve this.*

Schlumberger have introduced a flare stack system that burns hydrocarbons whilst producing no unburnt hydrocarbon fallout and no visible smoke. As a result there are no oil spill cleanup costs and reduced pollutant loading on the environment. Its capacity is 9000 bopd. It is referred to as the Evergreen burner and is designed specifically to dispose of all types of well test effluent. Financial support from the EC Thermie programme and scientific input from the Institut Français du Pétrole launched a project to develop am efficient flare system in 1993. By designing the flow of air to the flame, Total has developed an onshore gas burner that burns efficiently and does not release smoke into the environment (Total, 1997).

6.2.4.12 Power Generation

ENVIRONMENTAL ASPECT
Atmospheric Emissions from Combustion Units

UK ENVIRONMENTAL REGULATORY CONTROL
- Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000

MITIGATION MEASURES
Except for reduced power demand and improved utilisation of energy in the offshore processes, emissions can be reduced by:
- *Improved efficiency in power generation*
- *Improved combustion technology*
- *Cleaning up of the exhaust.*

Main source of CO_2 is the combustion of fuel gas for power generation processes. Optimisation of energy usage and increased combustion efficiency would reduce CO_2. CO_2 emissions may be reduced by CO_2 re-injection into depleted reservoirs or disposed of in the deep ocean. Diesel engines are highly efficient combustion engines and do not produce a significant amount of evaporative emissions. The fuel is completely converted to CO_2 and H_2O, CO and HCs are quite low. Nitrogen oxides and particulates are a problem for diesel. Most of the sulphur in diesel fuel is converted into SO_2, and emitted as gas. Optimisation of energy usage and increased combustion efficiency would also reduce nitrogen oxides and SO_2. Nitrogen oxides (NO_X) may be reduced by flue gas "denoxing" using catalysts or injecting steam or water into the combustion chamber. Dry Low Emission combustion technology for gas fuelled turbines can reduce NOx formation rates by reducing temperature in combustion engines (NOx formation rates are temperature formation rates are temperature dependent). Selective Catalytic Technology cleans exhaust from gas and diesel fuel engines.

6.2.4.13 Maintaining drill fluid chemistry, and minimising waste for disposal

ENVIRONMENTAL ASPECT
Cleaning chemicals and waste generation

UK ENVIRONMENTAL REGULATORY CONTROL
- Food and Environment Protection Act 1985
- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)

MITIGATION MEASURES
The properties of mud systems that are related to influencing the extent of pollution are dispersibility, solids control and dewatering. Dispersibilty potential is dependent upon the chemistry of the mud. Low dispersibility muds are desirable however these tend to be toxic. Thus the challenge is to develop low toxic muds with low dispersibility.

Solids control equipment ensures that the maximum volume of drilling fluid is recycled into the mud system. Equipment includes vibrating screens, hydrocyclones, decanting centrifuges and mud cleaners. This does not represent the configuration of a solids control system, which may use any combination of equipment to achieve a mud system objective. Vibrating screens (shale shakers) of various sizes remove cuttings from drilling fluids but do not remove expensive weighted material such as barite. Hydrocyclones (desilters, desanders and clay ejectors) for liquid solid separation spin the suspension and the strong centrifugal forces cause the mud and suspended cuttings to separate. By controlling the pressure across the hydrocyclone the mud flows through the overflow and the cuttings sludge is emitted from the underflow. Decanting centrifuges can salvage 90%-95% of barite. They work by rotating at high speed throwing particles against the side. These barite particles are conveyed toward the underflow to be collected and returned to the mud system. Where OBMs are used, diesel is recycled and solids discharged for disposal. Mud Cleaners (silt separators or sand separators) are designed to remove solids whilst retaining barite. They consist of a vibrating screens and desilters. The primary objectives of solids control equipment is to remove drill cuttings but maintain weighting material such as barite, and control and maintain drill fluid chemistry whilst drilling. Direct environmental expenditure is incurred in those technologies and techniques that clean, treat and dispose of cuttings, reduce wastes and recycle materials i.e. those that ensure that the operator minimises any environmental liability. The disposal and treatment of cuttings is discussed in 6.2.4.16.

Dewatering is a technique used where no disposal on-site is permitted. Consequently it is desirable to minimise the volume of drilling fluid used to reduce onsite storage and offsite disposal costs. Dewatering is the technology to separate the water from WBMs for reuse in the mud system. It also significantly reduces the volume of liquid waste that is destined for ultimate disposal.

Spent and unused OBM & SBMs may be conditioned and re-used. Those that are rented are returned to the supplier. WBMs are discharged offshore.

6.2.4.14 Rig deck drainage using pressurised water hoses

ENVIRONMENTAL ASPECT
Drainage of drilling areas can have a very high volume of oily and chemical discharges to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997

MITIGATION MEASURES
Lube/fuel oil tanks and machinery spaces will be fitted with bunding to collect spilllages of oil or oily waste. These bunded areas have drains which connect to the bilge storage tank. Oily wastes may be transferred from the bilge storage tanks to waste oil storage tank for shipment ashore, treatment and disposal. The treatment of oily wastes is detailed in 6.2.4.16

6.2.4.15 Facility and standby vessel ballasting, and standby vessel bilge water discharges

ENVIRONMENTAL ASPECT
Ballast water discharged to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislation controlling the introduction of non-native species into UK waters
- Pending international legislation controlling the introduction of non-native species into UK waters from ballast water (a proposed Annex VII to MARPOL), there are IMO Guidelines for the control and management of ship's ballast water to minimise the transfer of harmful aquatic organisms and pathogens
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Prohibition of oily discharges inside the 3nm limit
- Ships delivered before 6/7/93 – discharges are prohibited unless vessel is on a voyage, is 12 nm from land and the oil content is less than 100ppm
- Modern ships – discharges are prohibited unless vessel is under voyage and the oil content is less than 15ppm
- Vessels greater than 400 gross registered tonnes must have an oil/water separator, oil sludge tanks, a Shipboard Oil Pollution Emergency Plan, a UK Oil Pollution Prevention Certificate and an Oil Record book

MITIGATION MEASURES
If the facility has been constructed in the UK, there is little risk of introducing non-native species. Under the Merchant Shipping (Prevention of Oil Pollution) Regulations 1996, the Maritime and Coastguard Agency has issued instructions to marine surveyors to ensure that adequate pollution prevention equipment is fitted to all ships. This includes a survey of a ship's structure. They detail the conditions required for the issuing of oil pollution prevention certificate that requires renewal every five years (The Maritime & Coastguard Agency, 1999). To avoid the contamination of ballast water with hydrocarbons a Segregated Ballast Tank System is fitted that completely separated ballast water from the cargo oil and fuel oil systems. Since the North West European Waters were classified as a 'Special Area', the UK has confirmed that is has adequate facilities for the reception of dirty ballast and tank washing water from vessels operating through out the area. (Such facilities are required under the Prevention of Oil Pollution (Reception Facilities) Order 1994 & The Merchant Shipping and Maritime Security Act 1997). Other equipment includes oil-water separating equipment; oil filtering equipment; Oil Discharge Monitoring & Control System (ODMC) including 15 ppm oil in water engine bilge alarm; and slop tanks (For fuel tank washings, oily sludge, and dirty ballast water). Facility machinery space drainage discharge has to comply with 15 ppm and thus monitoring and filter equipment is required to ensure compliance.

6.2.4.16 Disposal of sewage, canteen, medical and other facility/vessel wastes

ENVIRONMENTAL ASPECT
Solid waste discharged into the sea; Hazardous and Special Waste disposed onshore

In a 1995 survey of vessels and their wastes, carried out by Environment Resource and Technology, the following for standby vessels was recorded:
Maximum number of people at Sea: 12-15
Duration at sea: Maximum 28 days, time in port ½ day
Deck and domestic waste: 1-2kg/day/person
Special waste: <0.5 tonne/year
Scrap metal: <0.5 tonne/year
Black water/grey water: 300 dm^3/day/person (sewage holding tanks common)
Other – davit/securing wire: 50kg/year; pyrotechnics: <20kg/year; drugs and medicines: <1kg/year

For mobile drilling rigs (semi-submersibles):

Maximum number of people at Sea: 70-100 (max 150, min 4)
Duration at sea: Permanently
Deck and domestic waste: 5-15kg/day/person

Special waste: <5 tonnes/year (rig), <5 tonnes/year (chemical drums)
Scrap metal: 20-35 tonnes/year
Black water/grey water: 200-300 dm^3/day/person (full sewage treatment common)
Pyrotechnics: <20kg/year

On average it may be estimated that one well generates 1200 tonnes of cuttings, which on dispersal would disperse to 1000 tonnes on settling. Given dispersion over time that amount may reduce to 750 tonnes.

UK ENVIRONMENTAL REGULATORY CONTROL

- Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1998
- Environmental Protection Act 1990; Environmental Protection (Duty of Care) Regulations 1991; Environment Act 1995; Special Waste Regulations 1996; Waste Management Regulations 1996; Controlled Waste Regulations 1992; Merchant Shipping and Maritime Security Act 1997; Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) Regulations 1996
- No legislation in effect offshore with respect to sewage from offshore installations
- *Voluntary Harmonised Offshore Chemical Notification Format*
- A standby vessel is required to be present at all times within 5 nautical miles of the installation under the Offshore Installations (Prevention of Fire and Explosion and Emergency Response) Regulations 1995

MITIGATION MEASURES

Disposal Offshore

By law food wastes produced from vessels will require treatment before offshore disposal. This treatment enhances biodegradation by breaking up the food wastes to maximise particle surface area.

An operator is not required to obtain a licence to discharge sewage. The operators may reduce the extent of the impacts by monitoring discharge density, flow rate and ambient water current. Beyond the operators' control are current speeds, wind conditions and sub-surface flow, which may affect the scale of an impact's influence

WBMs are discharged offshore. HOCNF encourages the use of chemicals that have a low toxicity to marine fauna. For this reason WBMs may be used and contain chemicals that are approved by the DTI as being low toxicity. A greater volume of WBM is required than OBM to drill therefore increasing the quantity discharged. For this reason careful management may ensure that the trigger limits for the groups of chemicals under HOCNF are not exceeded.

There are a number of offshore disposal options available to operators for hazardous cuttings waste:

- *large silos or concrete storage tanks on the seabed*
- *re-injection into reservoir formation;*
- *burial in a deep sea pit*
- *spreading*
- *gravel dumping on top*
- *capping*
- *insitu bioremediation*
- *leave undisturbed*

Cuttings re-injection cannot be used in all applications as it requires an injection well.

Disposal Onshore

Transport to shore does not solve discharge problems it merely transfers them to a terrestrial location. Other wastes from both facilities and vessels, particularly those that are hazardous will require segregation and safe disposal on land. Duty of Care Regulations detail disposal controls and thus effective compliance requires the development of a waste management plan. Such plans are mandatory for vessels (The *Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1998)*

There are various treatments available for the onshore disposal of cuttings and oily sludges and include: stabilisation; bio-remediation; thermal desorption and solvent extraction. Cuttings stabilisation converts the sludge to a chemically stable form that resists leaching. It is usually involves lime immobilising water based muds as the process is suited only to low hydrocarbon concentrations. The stabilisation results in solidification, which may either, be disposed of in landfill or used in civil engineering projects (Amiry, Sutherland & Martin 1997, Bouchelaghem & De Rochebouet, 1998). Bio-remediation or landfarming enables bacteria to biodegrade hydrocarbons to 75%, which are retained in the soil's top 8 inches. A two year study identified that OBM cuttings have no phytotoxic effects on the germination of corn and that no petrogenic hydrocarbons were detected in the grains of successive generations of corn (Ladousse et al., 1996). Total petrogenic oil content in the soil may be reduced to 0.5%, which is a Special Waste under UK regulations (Ness, 1999). The spreading of water based drilling waste has been demonstrated to reclaim acid-sulphate soils provided that heavy metal critical levels in the soil are not exceeded (Vásquez et al., 1996). The solid residue from stabilisation and bio-remediation has leachate potential that may contaminate water including groundwater. Thermal desorption (incineration) converts cuttings sludge into less bulky and less toxic material. It involves either directly or indirectly applying a flame to the sludge to vaporise oil and water which is isolated, recovered and recycled. The oil content on cuttings is reduced to below 0.1% by this process however potential heavy metals pose waste classification problems. Thus the solids residue has the potential to contaminate inland waterways and groundwater (Ness, 1999). Due to the latent heat of vaporisation of water, drilling fluids with high water content severely reduce the throughput efficiency of thermal systems. Solvent extraction (wash system) utilises a solvent e.g. hexane, to extract contaminants from cuttings. A centrifuge then separates the solvent and solids. The cutting particles have a residue of hexane prior to disposal in a landfill. The solvent and solute (contaminants) are then separated so that the solvent may be reused.

Recycling onshore

Central Mudplant & Fluid Services BV of Holland recover all drilling mud that it supplies with cuttings and treats them using a distillation technique. All products of this technique are recycled.

Lubricating oil may be recycled using a patented solvent extraction system that operates without the use of heat or pressure thus improving the eco-efficiency of the process and ensuring the process is economical (Interline Resources Corporation, 1999).

Bio-remediation is discussed under the treatment of drill cuttings above, however it may also be used to treat other wastes such as oily tank sludge and hydrocarbon-stained soil. Composting is a form of bio-remediation which uses micro-organisms to assimilate the source of carbon and energy by breaking down and reducing the hydrocarbon content. Total has been using *composting to treat hydrocarbon wastes and after 9 months it was recorded that oil content levels had dropped to 0.2% of the soil's weight (Total, 1997).*

A safe, practical and economically feasible alternative to current waste management practices for large volumes of hazardous petroleum industry wastes can be achieved through geological disposal in salt solution caverns. Wastes are placed in as a oil field slurry, and then undergo a gravity separation process. The solids settle to the bottom of the cavern while the lighter brine and hydrocarbons rise to the surface where they can be removed and recycled. If the geological conditions are right, the salt solution cavern placement offers exceptional security (Davidson & Dusseault, 1997).

Mooring barges for long periods of time is not a practicable option in the North Sea due to the severe weather and sea conditions. An average 3-day platform cuttings storage is the generally accepted norm.

6.2.4.17 Equipment Cooling

ENVIRONMENTAL ASPECT
Overboard discharge of thermally polluted water

UK ENVIRONMENTAL REGULATORY CONTROL
- No environmental legislation

MITIGATION MEASURES
Aeration and increased dispersion by discharging above the surface of the sea will cool discharging thermally polluted water.

The use of seawater for cooling and/or firewater purpose presents a risk of biological growth (biofouling) in pipe work and heat exchanger plates. This can cause blockage in pipes and valves, biologically induced corrosion and reduced cooling efficiency. Consequently treatment is required to prevent this. Chlorine and other chemical biocides, aluminium and copper are often used against biofouling caused by barnacles, mussels, hydroids, bacterial and microalgal slimes. Antibiofouling technologies may influence farther afield. Any technological development, which can treat the problem without creating another, is beneficial

Antibiofouling technology has been developed that reduces the use chlorine and other biocides. This includes BFCC copper-chlorine offshore units. This involves electrolysis. BFCC is considered to require less energy and maintenance than conventional treatments. The supplier Baker Hughes Process Systems (BHPS), to ensure a lower environmental impact than the use of chlorine and chemicals, states the use of a low concentration copper and chlorine solution in conjunction with a dosing strategy. This strategy is referred to as patented Sequence Target Dosing technology

Electrochlorination is an alternative to treat biofouling with sodium hyprochlorite (bleach). Treatment with chemicals requires bulk storage facilities. Chlorine is produced from seawater or brine by electrolysis. The cooling water is dosed with copper and chlorine. Other treatments include the use of aluminium. This process too can be used offshore but appears from tests to be not as effective and potentially more environmentally damaging, when compared to BFCC. Such equipment is found to treat any sea water system on installations, tankers and other merchant vessels.

6.2.4.18 Vessel/helicopter transportation

ENVIRONMENTAL ASPECT
Exhaust emissions to air; Disposal of helifuel samples onshore

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) Regulations 1996

MITIGATION MEASURES
Exhaust emissions from operation of vessels and helicopters are inevitable. Zero emissions are impossible even with electrical power or the use of clean fuels such as hydrogen. Equipment with zero emissions produce a pollution displacement effect i.e. from the equipment to fixed power generating plants or industrial plants. Local pollutants will be reduced, but life-cycle analysis will show that resource use or global impacts will remain

Improving the efficiency of the engines and maintaining equipment will improve the local environmental quality. See 6.2.4.2.

Helifuel samples are disposed of with other oily wastes into a bilge storage tank for onshore treatment and disposal. See 6.2.4.16.

6.2.4.19 Rig servicing

ENVIRONMENTAL ASPECT
Washing water from cleaning facility discharged to sea; Atmospheric emissions from painting antifoulant on topsides; Discharges and emissions from support vessels and coastal port development

UK ENVIRONMENTAL REGULATORY CONTROL
- For marine and atmospheric discharge controls *see 6.2.2.1 & 6.2.4.2.*
- New Annex to the International Convention for the Prevention of Pollution from Ships 1973, as modified by the Protocol of 1978 (MARPOL 73/78) prohibiting the use of toxic anti-fouling paint (particularly that containing the organotin tributyl tin (TBT).

- Environmental Protection Act –Integrated Pollution Control (IPC) and Local Air Pollution Control (LAPC)

MITIGATION MEASURES
Use of biodegradable cleaning products will reduce the impact of cleaning fluids offshore with negligible marginal environmental expenditure. For minimising the impact of marine and atmospheric discharges see 2.1 and 3.2. The products used for washing facilities are either category 0 or 1 under the old OCNS format. Under the new HOCNF system it will be after the 1 January 2000 that recategorisation of all the washes into Groups is achieved.

Alternatives to TBT paint include copper-based coatings and silicon-based paints, which make the surface of the ship slippery so that sealife will be easily washed off as the ship moves through water. Further development of alternative anti-fouling systems is being carried out. Underwater cleaning systems avoid the ship having to be put into dry dock for ridding the hull of sealife, while ultrasonic or electrolytic devices may also work to rid the ship of foulants (IMO, 1999).

6.2.4.20 Suspending a well

ENVIRONMENTAL ASPECT
Presence of structure, entanglement of fishing gear, presence of anodes and coatings

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislative controls

MITIGATION MEASURES
A suspended well by definition is one that is capable of being re-entered and UKOOA's Guidelines for the Suspension and Abandonment of Wells detail appropriate suspension procedures dependent on the characteristics of the underlying formation. A single temporary barrier is recommended for normally pressured water bearing zones. Two temporary barriers are required for the isolation of hydrocarbon bearing or overpressured permeable zones from surface.

Suspended wells of no further use have to be converted to abandoned wells. The suspended wells present a potential hazard to fishermen. In 1997 there were 400 suspended wells on the UKCS and BP owned 200 of them. The operator commenced a decommissioning project to reduce that number by 2/3rd. BP's project used a contracted vessel to plug the wells and in the process it was identified that 60% of the suspended wellheads decommissioned in the project were covered by fishing nets (Morrice & Kirby, 1997). UKOOA and the UK Seafish Industry Authority have developed a seabed information service to avoid the risk of any accidents. The service provides information on any seabed obstructions and sea-surface facilities.

6.2.4.21 Abandoning a well

ENVIRONMENTAL ASPECT
Removal of structure, metal emissions to the seabed

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
UKOOA's Guidelines for the Suspension and Abandonment of Wells recommend the use of two extensively tested barriers down hole. These are permanent barriers which seal the well by 'plugging'. The casing strings are removed to a depth of 3 m (10 ft) below the seabed. All other obstructions are removed and the well's method of clearance is discussed with all the relevant fishing organisations in the area. Procedures of this nature serve in themselves to ensure no future environmental impact and may be conducted under an Operator's environmental management system to minimise any impact to the environment.

UKOOA and the UK Seafish Industry Authority have developed a seabed information service to avoid the risk of any accidents. The service provides information on any seabed obstructions and sea-surface facilities

6.2.5 *Drilling - accidents*

6.2.5.1 *Mobilisation and positioning of facility and support vessel, crane vessel and cargo barge*

ENVIRONMENTAL ASPECT
Overboard spillage of chemicals, hydraulic oil, or dropped objects

UK ENVIRONMENTAL REGULATORY CONTROL
- Food and Environment Protection Act 1985
- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Petroleum Operations Notice 1

MITIGATION MEASURES
Risk assessment studies and the safety case produced for a facility, together with effective management will reduce the probability of accidental spillage or dropping of objects. If a vessel has a plan in place already HSE training and management can improve handling practices on decks and thereby prevent the accidental dropping of objects overboard. It would be an infringement of the Food and Environmental Protection Act to leave dropped objects on the seabed. Operators may carryout post drilling surveys using an ROV to identify if any objects are present before removing them.

If the operator has a policy of using chemicals, the majority of which are from Group E, and effective management ensures that the discharge is 'small', i.e. it is a spillage, then the environmental impact from such accidents in total will be negligible. Chemicals used are also subject to a Control of Substances Hazardous to Human Health assessment that identifies toxic chemicals and recommends safe handling procedures. Synthetic absorbent materials have been developed to soak up chemicals and are not wetted by water improving their pollutant absorbency efficiency. They are available as booms systems that surround a spillage, and as pillows, mats and sheets that can be deployed in places inaccessible to machinery. The absorbent material floats on water and is thus easy to collect when sea conditions are slight and remove. One such example is Sea sweep, which is a woodwaste product ('pin chips') designed to float and absorb oil and chemicals and not water. 1lb of Sea sweep may absorb 3.5lbs of chemical (Sea sweep, 1999).

Oil spill contingency operations will reduce the impact of an oil spill. The severity of the spill will depend upon the biodegradability and bio-accumulation potentials of the spilt oil, the energy of the environment into which the oil has been spilt and the efficiency and nature of the clean-up method used.

6.2.5.2 *Collision and Groundings*

ENVIRONMENTAL ASPECT
Overboard spillage of chemicals or solids, dropped objects

UK ENVIRONMENTAL REGULATORY CONTROL
- Food and Environment Protection Act 1985
- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- International collision regulations, harbour speed limits and local Port Authority requirements

MITIGATION MEASURES
Risk assessment studies for specific areas or routes will identify significant risks of collision. There are a number of factors that will mitigate against risk of collision: proper and competent pilotage; adequate tug capability; separation, monitoring and control of traffic, minimisation of crossing zones; and, for vessels transporting fuel, the use of double-hulled and segregated cargo tankers see 6.2.10.3. One of the duties of standby vessels is to intercept ships that have failed to respond to radio notification that states that failure to change course will infringe the facility's 500 m and risk collision.

Powered groundings are subject to the same mitigation measures as those employed to reduce risk of collision. Drifting groundings are avoiding using anchors or dynamic positioning thrusters.

See 6.2.5.3 & 6.2.5.1 for oil, chemicals and dropped objects.

6.2.5.3 *Drilling*

ENVIRONMENTAL ASPECT
Venting of gas from gas surge or kick, toxic gases encountered, mishandling of chemicals with spillage to sea, blowout releasing mud cuttings, oil, gas, condensate and mud additives to sea and air; Loss of drilling mud due to blockade of mud cleaners;

UK ENVIRONMENTAL REGULATORY CONTROL

- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Petroleum Operations Notice 1
- Food and Environment Protection Act 1985

MITIGATION MEASURES

Lying casing during the drilling process prevents unstable formations from caving in thereby hindering operations. One of its functions as part of a pressure control system is to prevent a kick or blowout from occurring. This is achieved in conjunction with a drilling mud carefully designed to apply the correct hydrostatic pressure to the base of the wellbore to prevent an inward flow of oil and gas when entering production zone, whilst being able to maintain drilling efficiency and transport rock cuttings to the surface. A loss of containment has catastrophic safety and environmental impacts

Casing provides structural support for blowout preventers (BOPs). In the event of uncontrolled flow of gas and oil to the wellhead, BOPs close off the wellhead and shut-in the flow from the marine riser before the wellbore pressure is brought under control

To deal with pressure control problems, well control and contingency plan procedures are developed. This may include training facility crews, regular testing of BOP equipment, BOP test drills and standard procedures to deal with a blowout. Whilst loss of containment presents a local environmental risk, the economic consequences may render the project insolvent

Oil spill contingency plans are required to be development, practised and updated under UK law. Thus environmental risk assessments are undertaken, response ability evaluated (usually involving the employment of oil spill combat specialists (Briggs Marine) and an oil pollution vessel for a drilling facility) to identify response capability, and training and practice exercises undertaken to test the competency of the plan (Oscar, 1996). The size and probability of oil spill based upon UK oil and gas industry statistics:

- *<1 tonne: 1 per year*
- *1-25 tonnes: 1 per year*
- *25-100 tonnes: 1 in 100 years*
- *100-1,000 tonnes: 1 in 1,000+ years*
- *>10,000 tonnes: 1 in 10,000+ years.*

In addition - generic oil spill contingency manuals which can be continuously updated are useful aids for: contacts; step-by-step instructions for assessment, containment and recovery, in-situ burning, public relations, job descriptions and function, and documentation; and are-specific maps.

Oil spills are treated under three tier systems –

Tier 1 – a spill which can be dealt with the resources immediately available to an operator

Treatments available to the operator include:

- *natural dispersion and degradation*
- *use of dispersant to assist the natural dispersion process*
- *in-situ burning (under optimal conditions is considered to be 98% efficient at removing oil (Allen, 1990)*
- *mechanical containment and recovery – use of booms, skimmers and/or sorbents pumps and boats. The deployment of booms and effective skimming can only occur in the most ideal sea states and favourable spill configuration. Thus adverse weather conditions may render equipment useless, but favour natural dispersion and degradation (Gilliver et al, 1996).*

Tier 2 – a spill which cannot be dealt with by the resources immediately available requiring local or regional assistance

Tier 3 – a spill which requires national or international resources to be deployed (Salt, 1998)

Oil spill clean-up techniques include boom systems, pumps, dispersants and absorbents. There are many companies providing clean-up expertise in this area and are those that are based in the UK are represented by the British Oil Spill Control Association. Boom systems work by containing floating oil so that it may be recovered by extraction pump equipment. Large excavation equipment may collect up to 3000 bbl of oil per hour under optimal conditions. Specialised equipment has been designed for rocky shorelines, harbours and anywhere, where offshore clean-up technology is inappropriate. It uses a rotating stiff brush to 'lick' oil from surfaces and may also be used for chemicals (Lamor Rock Cleaner). Dispersants are demulsifiers that break up oil to accelerate the dispersion process and promote biodegradation by increasing the surface area of oil for micro-organisms to attach onto. However studies have demonstrated that aerial spraying of dispersants is a poor form of environmental mitigation. Synthetic absorbent materials have been developed to soak oil and chemicals and are not wetted by water improving their pollutant absorbency efficiency. They are available as booms systems that surround a spillage, and as pillows, mats and sheets that can be deployed in places inaccessible to machinery. The absorbent material floats on water and is thus easy to collect when sea conditions are slight and remove. One such example is Sea sweep, which is a woodwaste product ('pin chips') designed to float and absorb only oil and chemicals and not water. 1lb of Sea sweep may absorb 3.5lbs of oil (Sea sweep, 1999). Briggs Marine offers membership to companies of a Marine Oil Spill Response club to ensure effective oil or chemical spillage.

Cleaning up oil and chemical contaminated cuttings from the seabed is an environmental liability, which is receiving attention. Cuttings pile form when a mineral oil based mud has been used and the hydrodynamic energy of the deposition area is low. Technology is being developed to clean up these hazardous waste piles. Developing the right technology and procedure is affected by environmental sensitivity, as any investment would be futile if the clean-up generated environmental concern. Technologies include: Pnuema hydrostatic pump system literally 'vacuums' deposited cuttings at a rate of between $80m^3/h$-$180m^3/h$ for storage in surface tanks; and, the JETROP system that spreads contaminated cuttings using a highly pressured jet of water.

There are a variety of technologies available to monitor offshore discharges, using light presents an cost effective approach. Chemicals in the water offshore may be detected using Microtox – a screening technique that uses freeze-dried photoluminescent bacteria. The degree of light inhibition that a sample of water containing micro-organisms produces, is a simple measure of the toxicity. Another photometer has been developed to monitor traces of oil in water (the Sigrist Photometer AG) using *ultraviolet fluoresence. Some large aromatic molecules contained in crude oil have fluorescent properties that can be excited by UV radiation to emit a lower frequency of visible light.*

6.2.5.4 Structural failure

ENVIRONMENTAL ASPECT
Riser failure discharging product, rig collapse - potential for damage to established wells

UK ENVIRONMENTAL REGULATORY CONTROL

- Offshore Installations (Safety Case) Regulations 1992

MITIGATION MEASURES
Combined Operations Safety Case ensure that the movement of any drilling facility is undertake in a way that poses no threat to integrity of wells. The wells will be shut during the movement of a drilling facility.

6.2.5.5 Connection failure

ENVIRONMENTAL ASPECT
Release of transferred product (products, drilling muds, cuttings and diesel fuel)

UK ENVIRONMENTAL REGULATORY CONTROL

- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Petroleum Operations Notice 1

MITIGATION MEASURES
In the event of hose failure, valves may be designed to close rapidly either manually or automatically in the event of a break

If the operator has a policy of using chemicals, the majority of which are from Group E, and effective management ensures that the discharge is 'small', i.e. it is a spillage, then the environmental impact from such accidents in total will be negligible. Chemicals used are also subject to a Control of Substances Hazardous to Health (COSHH) assessment that identifies toxic chemicals and recommends appropriate handling procedures. For chemical spillage see 6.2.5.1. For oil spill contingency see 6.2.5.3.

6.2.5.6 Facility utilities and logistics

ENVIRONMENTAL ASPECT
Helifuel spillages during refuelling operations: release of halon in case of fire

UK ENVIRONMENTAL REGULATORY CONTROL

- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- European Commission Regulation on substances the deplete the ozone layer 91/594/EEC as amended by 3952/92, which implements the Montreal Protocol (1/1189) (as amended)
- European Commission Regulation on substances the deplete the ozone layer 3093/94.

MITIGATION MEASURES
CFCs and other Halons have long atmospheric lifetimes, between 65 years and 130 years. There are already enough of these compounds that are present in the atmosphere to give elevated stratospheric chlorine concentrations until 2100. Upstream operations, due to the exceptional working conditions, require the most efficient safety substances and equipment available. The proposed phase out of Halon by companies has been slow, as there has been no satisfactory safer and environmentally friendlier substitute(s) in sufficient quantities found so far. Consequently, Halon fire production systems should be used only where there is no alternative possible.

The use of hydrochlorofluorocarbons (HCFCs) has been proposed as they contain hydrogen atoms, which makes then likely to break down in the troposphere. Thus, only a small proportion of emitted compounds should reach the stratosphere. Ideally, all chlorinated compounds should be replaced with compounds, which do not release any ozone destroying species (O'Neill, 1993).

6.2.5.7 Onshore Waste Disposal

ENVIRONMENTAL ASPECT
Waste disposed of in landfill may leach contaminants into soil, groundwater and surface water.

UK ENVIRONMENTAL REGULATORY CONTROL

- Environmental Protection Act 1990; Environmental Protection (Duty of Care) Regulations 1991; Environment Act 1995; Special Waste Regulations 1996; Waste Management Regulations 1996; Controlled Waste Regulations 1992

MITIGATION MEASURES

There are a number of technologies available to ensure that little waste oil enters the terrestrial environment. The Dutch company, SAS, has developed portable equipment that treats oil-polluted soil and water in situ. The oil is separated for re-use and thereby aims to eliminate the requirement to dispose of large volumes of Special Waste. Central Mudplant and Fluid Services BV of Holland have developed 'Wastebuster', a biological water purification system that digests oil, fat, heavy metals and aromatic compounds producing CO_2 and water. The water may be recycled or discharged as wastewater. Plasma incineration (plasma torch) sends a strong electrical current though rarefied gas, which creates plasma (an intensely hot gas - 10,000^oC), and solidifies and stabilises toxins in soil into inert and harmless glassy rocks suitable for road gravel. Plasma incinerators burn efficiently, emitting one fifth as much gas. Some designs capture this gas, which may be used as fuel. Research has been undertaken into using cold plasma to destroy toxic vapours, for example from VOCs and convert them into less harmful products including CO, CO_2 and water (Frosch, 1995).

Specialised equipment has been designed for rocky shorelines, harbours and anywhere, where offshore clean-up technology is inappropriate. It uses a rotating stiff brush to 'lick' oil from surfaces and clean up chemical spills (Lamor Rock Cleaner). Synthetic absorbent materials have been developed to soak oil and chemicals and are not wetted by water improving their pollutant absorbency efficiency. They are available as pillows, mats and sheets that can be deployed in places inaccessible to machinery. The absorbent material floats on surface-water and is thus easy to collect.

6.2.6 Production - routine

6.2.6.1 Facility

ENVIRONMENTAL ASPECT
Physically covering parts of the seabed; Power Generation Atmospheric Emissions

UK ENVIRONMENTAL REGULATORY CONTROL
- Prior consent from the Secretary of State is required for the siting of a drilling installation (Section 34 of the Coast Protection Act 1949), Continental Shelf Act 1964
- Notices to Mariners (M Notices) or navigational warning
- DETR Merchant Shipping Regulations
- Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000
- No Statutory CO_2 Emissions Trading System

MITIGATION MEASURES
Construction Notification is submitted to the Health and Safety Executive 28 days prior to activity. Buoys and Admiralty charts mark the 500m-exclusion zone (0.8 km²) and facility. By law, an operator consults and notifies, during the preparation of an environmental statement, fishermen and other interested parties, including Ministry of Defence, The Archaeological Diving Unit (St. Andrews), British Telecommunications and Nature Conservation Organisations. An operator may appoint a fisheries liaison officer to undertake consultation with fishermen. Other consultations may be carried out with any other parties affected by the activity.

M Notices disseminate information of the location of production facilities, their pipelines and shuttle tanker routes to merchant shipping and fishing vessels.

For efficient power generation emissions see 6.2.4.12.

6.2.6.2 Primary Recovery

ENVIRONMENTAL ASPECT
Atmospheric emissions

UK ENVIRONMENTAL REGULATORY CONTROL
- Atmospheric emissions are monitored and recorded in database on emissions into the atmosphere which is managed by UKOOA

MITIGATION MEASURES
For efficient flaring see 6.2.4.11.

6.2.6.3 Secondary Recovery

ENVIRONMENTAL ASPECT
Water or gas injected into the reservoir to increase and maintain pressure – atmospheric emissions from fuel to power injection

UK ENVIRONMENTAL REGULATORY CONTROL
- Atmospheric emissions are monitored and recorded in database on emissions into the atmosphere which is managed by UKOOA

MITIGATION MEASURES
For efficient flaring see 6.2.4.11.

6.2.6.4 Tertiary Recovery

ENVIRONMENTAL ASPECT
Chemicals injected (e.g. surfactants and polymers) - atmospheric emissions from fuel to power injection

UK ENVIRONMENTAL REGULATORY CONTROL
- Atmospheric emissions are monitored and recorded in database on emissions into the atmosphere which is managed by UKOOA

MITIGATION MEASURES
For efficient flaring see 6.2.4.11.

6.2.6.5 Workovers and stimulations

ENVIRONMENTAL ASPECT
Venting of well pressure will result in the emission of gas to air and/or discharge of oil and chemicals (incl. acids, corrosion inhibitors, biocides and brines) to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Food and Environment Protection Act 1985

MITIGATION MEASURES
Wells are worked over to increase production, reduce operating cost or reinstate their technical integrity (Jahn et al.,1998). Vents may be to the atmosphere via bleed line to flare or to a closed drain system or to an open 'hazardous' drain. Good practice will ensure that the fates of vented products have minimal environmental impact. Pressure testing equipment for integrity prior to use highlights any potential environmental risks. Formation damage may cause actual well production to fall below the well potential warranting a workover. Under such circumstances the impairment may be treated using acid. The acid is then back-produced if possible along with the impairing products, and discharged to sea. Acids used are strong and toxic including HCl and HF. However if properly used these fluids should not contaminate produced water and be caught separately and neutralised (Orszulik, 1997). Chemicals used have to be approved either by SERAD or MAFF, and categorised under HOCNS. Acid neutralisers are used in the disposal of acids and combat accidental acid spills, which are a serious threat to human life, and project economics, as clean-up costs are high. The neutralisers themselves, (limestone, high-calcium quicklime, hydrated lime, dolomite quicklime; soda ash, caustic soda; magnesium oxide, magnesium hydroxide; potassium hydroxides; ammonia triethanolamine) pose significant health risks if used incorrectly. Safer, easier-to-use neutralisers are being developed including Upright Inc.'s WYK acid-bond products that buffer the neutralisation process and the encapsulate vapours released, forming a neutral gel that is easy to handle and dispose of (Shanley, Silverberg & D'Aquino, 1999).

Aggressive attack of acids on the well hardware must be controlled and thus a corrosion inhibitor is mandated. Such inhibitors require additional intensifiers of contact time extenders. Effective metal intensifiers have the severe disadvantage of being exceedingly toxic to aquatic life as well as to humans. Copper salts are lethal to aquatic life at concentrations below 10 ppm. Antimony salts can also cause heavy metal poisoning when used in the required concentrations for inhibitor intensification. Low toxicity intensifiers are only recently available (Brezinski, 1999).

6.2.6.6 Crude Oil Processing – Primary and Secondary Separation & Acid Gas Removal – Sweetening (Heat treatment for heavy crudes); Light Oil Processing – Primary and Secondary Separation & Acid Gas Removal – Sweetening; Natural Gas Processing – Primary and Secondary Separation & Acid Gas Removal – Sweetening

ENVIRONMENTAL ASPECT
Separated gas surplus flared; Removal of any unwanted solids (salts), liquids, (Produced water, chemical additives – demulsifiers, corrosion inhibitors, defoamers, biocides, scale inhibitors, oxygen scavengers, wax inhibitors, and flocculants) or gases (H_2S, CO_2); Oily wastes and fallout of unburnt hydrocarbons; Dehydration and sweetening wastes (including VOCs and BTEX); Glycol Filters; Produced sand

UK ENVIRONMENTAL REGULATORY CONTROL
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)
- Chemical discharges are voluntarily monitored by industry and quarterly accounts are sent to the DTI, and recorded in their SCOPEC database
- No consent is required for the discharge of cuttings, Deposits in the Sea (Exemptions) Order 1985
- Atmospheric emissions are monitored and recorded in database on emissions into the atmosphere which is managed by UKOOA (Environmental Emission Monitoring System)
- No legislative controls over produced noise in water or air
- Flaring consent required from DTI – exemption from Section 3 of the Prevention of Oil Pollution Act is required

MITIGATION MEASURES
In order to achieve regulatory compliance for produced water discharge it is required to remove oil. This is known as deoiling and involves the separation of free oil suspended in the continuous water phase. Treatment is primarily split into a number of stages. The volume of produced water from an gas production platform is approximately 150x less than that discharged from a oil production platform.

Primary treatment, involves: initially gravity settlers; or coalescer units; followed by induced gas floatation units. Gravity separation systems involve allowing the oil to settle out of water and float to the top where it is skimmed off. Plate separators utilise two-stage plate packs, which allow the oil to coalesce, then separate out with suspended solids from the water stream. The induced gas floatation process disperses fin gas bubbles into a reaction chamber to suspend particles that ultimately rise to the surface and form a froth layer. Oil droplets and oil-coated solids, which are suspended in the water, attach to these bubbles as they rise to the surface, and are trapped in the resulting foam and are removed when the foam is skimmed from the surface. Floatation cells use two *different methods to induce gas into the produced water, either mechanical using a rotating impeller to create a vacuum to draw gas, or hydraulic injectors to aspirate gas into the produced water*

Secondary treatment involves using liquid/liquid hydrocyclone separation technology to further reduce the oil content in water. These are known as 'deoilers' and may be used prior to using a dehydrator cyclone that removes water from an oil continuous mixture. The hydrocyclone operates due to a pressure drop. Fluids are directed tangentially into the hydrocyclone. This causes the fluids to spin. The spinning motion generates strong centrifugal forces that cause the two immiscible liquids to separate. The centrifugal force generated varies over the length of the hydrocyclone and may reach up to 3000g. By controlling the pressure across the hydrocylone the lighter fluid flows through the overflow and the heavier fluid is forced down toward the underflow. Deoilers may clean the water stream to 10-30-50 ppm oil in water and have a 2-3 second retention time. 'Dehydrators' may concentrate oil to 90%-98%. Deoiler capacities depend upon available pressure and range from between 100-2,500 bwpd. If high efficiency performance is required at high flow rates, the required number of deoilers is installed in a pressure vessel in a multi-cyclone arrangement. A typical 200,000 bwpd deoiling facility requires 4 m^2. The advantage of hydrocyclones is that they contain no moving parts. Offshore they are used for produced water cleanup, free water knockout, wastewater treatment and downhole oil/water separation. The removal of dissolved organics, or salt, from produced water is not undertaken offshore. They are used elsewhere for oil the removal of oil and organics from groundwater, sewage and waste water treatment. The removal of dissolved organics from produced water occurs during onshore production.

Desanders are hydrocyclones (soild/liquid separation technology) used to remove produced sand from produced water streams. The theory behind its operation is identical to the removal of solids from drilling fluids detailed in 6.2.4.13. Desanders can separate 98% of particles from 3 to 108 microns. Large desanders can handle solid volumes in water of up to 30% whereas smaller units may handle 1%. Offshore they are used generally for produced water treatment but when used in conjunction with a wash system they may be used to clean oil from produced sand before it is disposed of offshore.

Hydrocylones are also used for gas/liquid separation including the removal of H_2S. The operational requirements are identical to the liquid/liquid hydrocyclone separation technology described above.

More recent technology includes the application of centrifuges, media filtration and membrane filtration. Centrifuges remove oil droplets down to 2 microns and reduce the oil in water content to 10 ppm. They consist of a separation bowl, a power transmission (gear and belt drive) and an electric motor. Media filtration uses a medium such as pecan, walnut shells to strip contaminants from the water. Contaminant removal of over 2 microns may be achieved under this process. Membranes are referred to as diffusion barrier technology and are able to reduce oil levels in water from between 500-150 ppm to less than 10 ppm in 30 days. The capacity of this technology is 70 bwpd.

Steptech units are designed to monitor hydrocarbons in produced water, bilge water and ballast water to ensure regulatory compliance. They are constructed in stainless steel, designed to be ready to operate offshore, and require low maintenance (Steptech Instruments Services Ltd, 1999).

Amine sweetening units are used to remove acid gases (H_2S, other sulphur species, and/or CO_2) from sour natural gas. VOCs and other hazardous air pollutnats are partially absorbed by the amine solution. Depending on the composition of the natural gas entering the sweetening unit and the gas throughput, these units may represent a significant source of VOCs and BTEX emissions if the acid gas stream from the amine-regenerator is discharged directly into the atmosphere (Skinner et al., 1999).

For efficient flaring see 6.2.4.11. For power generation emissions see 6.2.4.12.

There have been a number of projects in the Europe into assessing the impacts of produced water on marine animals. Of particular interest are the toxicity of chemicals in produced water and the recovery rate of ecosystems that have been observably affected. This interest has resulted in the development of CHARM, Chemical Hazard Assessment and Risk Management Model. This model assesses quantifiably the risks associated with discharge chemicals and can be used to facilitate decisions on different types of primary ECTs. Risk is assessed on the basis of a chemical's ecotoxicological, biodegradation and bioaccumulation potentials.

6.2.6.7 *Scale formation*

ENVIRONMENTAL ASPECT

Calcium, Barium, Strontium scales - Barium and Strontium scales naturally radioactive (low level) requiring disposal – Low Specific Activity scale

UK ENVIRONMENTAL REGULATORY CONTROL

- Radioactive Substances Act 1993
- Radioactive Substances (Phosphatic Substances, Rare Earths, etc) Exemption Order 1962

MITIGATION MEASURES

Scale formation may occur when injection water and formation water mix together, and can be precipitated in the reservoir as well as on the inside of the production tubing; this could be removed from the reservoir and tubing chemically (using acid HCl of HF) or mechanically scraped off the tubing. Handling and disposal of removed scale requires a licence from the Environment Agency for England & Wales and the Scottish Environmental Protection Agency for Scotland. Operators ensure that only authorised personnel deal with radioactive materials. The maximum allowable discharge to sea is <5Gbq/yr and any particles present have to be <1mm.

6.2.6.8 *Injection Water Treatment*

ENVIRONMENTAL ASPECT

Removal of fine solid materials and organic material (Bacteria and algae) using filters and biocides; Discharge of filter backwash and water softeners

UK ENVIRONMENTAL REGULATORY CONTROL

- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)

- Chemical discharges are voluntarily monitored by industry and quarterly accounts are sent to the DTI, and recorded in their SCOPEC database

MITIGATION MEASURES

Desanders are hydrocyclones (soild/liquid separation technology) used to remove solids from seawater streams prior to injection. The theory behind its operation is identical to the removal of solids from drilling fluids detailed in 6.2.4.13. Desanders can separate 98% of particles from 3 to 108 microns. Large desanders can handle solid volumes in water of up to 30% whereas smaller units may handle 1%. A solid state laser can identify the amount of solids in water. This identifies any solid with a diameter of 1μm or more. It may be used to assess whether solids removal equipment such as filters and hydrocyclones are effective. Chemicals used in the process have to be approved either by SERAD or MAFF, and categorised under HOCNS to minimise ecotoxicological effects.

6.2.6.9 Chemical Handling

ENVIRONMENTAL ASPECT

Unloading and on-platform handling, disposal of chemicals in containers onshore

UK ENVIRONMENTAL REGULATORY CONTROL

- Environmental Protection Act 1990; Environmental Protection (Duty of Care) Regulations 1991; Environment Act 1995; Special Waste Regulations 1996; Waste Management Regulations 1996; Controlled Waste Regulations 1992

MITIGATION MEASURES

See 6.2.4.9. If the operator has a policy of using chemicals, the majority of which are from Group E, and effective management ensures that the discharge is 'small', i.e. it is a spillage, then the environmental impact from such accidents in total will be negligible. Chemicals used are also subject to a Control of Substances Hazardous to Human Health assessment that identifies toxic chemicals and recommends safe handling procedures.

6.2.6.10 Wax and Asphaltene Formation

ENVIRONMENTAL ASPECT

Aromatic solvents or Acids discharged to sea

UK ENVIRONMENTAL REGULATORY CONTROL

- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)
- Chemical discharges are voluntarily monitored by industry and quarterly accounts are sent to the DTI, and recorded in their SCOPEC database

MITIGATION MEASURES

Long chain hydrocarbons will form solids (such as wax) at surface conditions, but will remain in solution at reservoir conditions. Waxes thus form where there is a drop in temperature and is most pronounced in tubing, flowlines and surface facilities. Precipitation of wax in the formation close to production wells where gas breakout and expansion causes a drop in temperature. Wax is removed by injecting heated aromatic solvents or acid.

Asphaltenes (high molecular weight substances) precipitate out of crude oil at pressures close to the bubble point. They are insoluble in non-aromatic solvents and their precipitation cannot be inhibited with chemicals. They are removed very slowly with various aromatic solvents. Formation damage due to asphaltenes is rare. Prevention can only be achieved by avoiding bottom hole pressures responsible for its formation. Asphaltenes react with acids, forming precipitates, which can cause significant damage often negating the anticipated benefit of the acid treatment.

6.2.6.11 Equipment cooling

ENVIRONMENTAL ASPECT

Discharges of large volumes of heated water treated with chlorine

UK ENVIRONMENTAL REGULATORY CONTROL

- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)
- Chemical discharges are voluntarily monitored by industry and quarterly accounts are sent to the DTI, and recorded in their SCOPEC database

MITIGATION MEASURES

See 6.2.4.17.

6.2.6.12 Gas safety purge

ENVIRONMENTAL ASPECT
Flaring of oil, gas and/or condensate

UK ENVIRONMENTAL REGULATORY CONTROL
- Flaring consent required from DTI – exemption from Section 3 of the Prevention of Oil Pollution Act is required

MITIGATION MEASURES
For efficient flaring see 6.2.4.11.

6.2.6.13 Power generation

ENVIRONMENTAL ASPECT
Atmospheric emissions from combustion units

UK ENVIRONMENTAL REGULATORY CONTROL
- Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000

MITIGATION MEASURES
For efficient power generation see 6.2.4.12.

6.2.6.14 Spent and unused chemicals

ENVIRONMENTAL ASPECT
Used solvents, cleaners, completion fluids and spent acids require disposal. Unused chemicals are either reused or returned to supplier or discharged offshore

UK ENVIRONMENTAL REGULATORY CONTROL
- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)
- Chemical discharges are voluntarily monitored by industry and quarterly accounts are sent to the DTI, and recorded in their SCOPEC database

MITIGATION MEASURES
See 6.2.4.9. If the operator has a policy of using chemicals, the majority of which are from Group E, and effective management ensures that the discharge is 'small', i.e. it is a spillage, then the environmental impact from such accidents in total will be negligible. Chemicals used are also subject to a Control of Substances Hazardous to Human Health assessment that identifies toxic chemicals and recommends safe handling procedures.

6.2.6.15 Facility deck drainage using pressurised water hoses

ENVIRONMENTAL ASPECT
Drainage deck during workovers and stimulations can have a very high volume of wastes - oily and chemical discharges to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997

MITIGATION MEASURES
Lube/fuel oil tanks and machinery spaces will be fitted with bunding to collect spilllages of oil or oily waste. These bunded areas have drains which connect to the bilge storage tank. Oily and chemical wastes may be transferred from the bilge storage tanks to waste oil storage tank for shipment ashore, treatment and disposal. All drains from the rig floor can be directed into the bilge storage tank.

6.2.6.16 Facility and support vessel ballasting

ENVIRONMENTAL ASPECT
Ballast water discharge to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislation controlling the introduction of non-native species into UK waters

MITIGATION MEASURES

See 6.2.4.4 & 6.2.4.15

6.2.6.17 Disposal of sewage, canteen, medical and other facility wastes

ENVIRONMENTAL ASPECT
Wastes discharged to sea. Hazardous and Special wastes disposed onshore. In a 1995 survey of vessels and their wastes, carried out by Environment Resource and Technology, the following for Northern North Sea Production platforms was recorded:

Maximum number of people at Sea: 50-300
Duration at sea: Permanent
Deck and domestic waste: 5-20kg/day/person
Special waste: 25-50 tonnes/year
Scrap metal: 100-400 tonnes/year
Black water/grey water: 250-400 dm^3/day/person (sewage macerators common)
Pyrotechnics: <20kg/year

the following for Southern North Sea Production platforms was recorded:

Maximum number of people at Sea: 50-80
Duration at sea: Permanent
Domestic waste: 1-2kg/day/person
Deck: 40-100 tonnes/year
Special waste: 15-25 tonnes/year
Scrap metal: 30-75 tonnes/year
Black water/grey water: 150-300 dm^3/day/person

UK ENVIRONMENTAL REGULATORY CONTROL
- Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1998 (1998 SI 1377)
- Environmental Protection Act 1990; Environmental Protection (Duty of Care) Regulations 1991; Environment Act 1995; Special Waste Regulations 1996; Waste Management Regulations 1996; Controlled Waste Regulations 1992; Merchant Shipping and Maritime Security Act 1997; Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) Regulations 1996
- No legislation in effect offshore with respect to sewage from offshore installations

MITIGATION MEASURES
See 6.2.4.16

6.2.6.18 Vessel/helicopter transportation

ENVIRONMENTAL ASPECT
Exhaust emissions to air. Disposal of helifuel samples onshore

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998

MITIGATION MEASURES
Helifuel samples are disposed of with other oily wastes into a bilge storage tank. See 6.2.4.18.

6.2.6.19 Facility servicing

ENVIRONMENTAL ASPECT
Marine discharges from cleaning facility. Atmospheric emissions from painting facility. Discharges and emissions from support vessels and coastal port development

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislative controls offshore
- Environmental Protection Act –Integrated Pollution Control (IPC) and Local Air Pollution Control (LAPC)

MITIGATION MEASURES
See 6.2.4.19.

6.2.7 *Production - accidents*

6.2.7.1 Collision of support vessel

ENVIRONMENTAL ASPECT
Overboard spillage of chemicals or solids, dropped objects

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- Food and Environment Protection Act 1985
- Petroleum Operations Notice 2

MITIGATION MEASURES
Risk assessment studies for specific areas or routes will identify significant risks of collision. Such studies are carried out in the preparation of an Oil Spill Contingency Plan and Environmental Statement. There are a number of factors that will mitigate against risk of collision: proper and competent pilotage; adequate tug capability; separation, monitoring and control of traffic, minimisation of crossing zones; and, for vessels transporting fuel, the use of double-hulled and segregated cargo tankers. One of the duties of standby vessels is to intercept ships that have failed to respond to radio notification that states that failure to change course will infringe the facility's 500 m and risk collision. This guiding action serves to minimise the risk of collision by a support vessel.

6.2.7.2 Production

ENVIRONMENTAL ASPECT
Venting of gas from gas surge or kick, toxic gases encountered, mishandling of chemicals with spillage to sea, blowout releasing mud cuttings, oil, gas, condensate and mud additives to sea and air

UK ENVIRONMENTAL REGULATORY CONTROL
- Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- MARPOL 73/78 Annex 2 Prevention of Chemical Pollution at Sea
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Food and Environment Protection Act 1985

MITIGATION MEASURES
Risk assessment studies for specific areas or routes will identify significant risks of loss of containment. Such studies are carried out in the preparation of an Oil Spill Contingency Plan (See 6.2.5.3) and sometimes in an Environmental Statement.

Loss of well control during production drilling can result in a loss of human life, loss of rig and equipment, loss of reservoir fluids, oil slick damage and the cost of bringing the well under control again. The two forms of controlling the well, primary and secondary control, are primarily designed not with the environment in mind but to protect against the loss of a discovered asset. Consequently BOP equipment installation and testing, the training of personnel in well control and contingency planning, are not environmental hazard mitigating measures. Any action to deal with and minimise the impact of a consequential environmental hazard, such as an oil spill, is a mitigation measure, see 6.2.5.3.

6.2.7.3 Mishandling of materials such as plastic sheeting, bags, containers, oil drums, lengths of wire and heavy objects

ENVIRONMENTAL ASPECT
Persistent waste released to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- Petroleum Operations Notice 2
- Food and Environment Protection Act 1985

MITIGATION MEASURES
Development of a waste management plan; If a vessel has a plan in place already HSE training and management can improve handling practices on decks and thereby prevent the accidental dropping of objects overboard. It would be an infringement of the Food and Environmental Protection Act to leave dropped objects on the seabed. Operators may carryout post decommissioning surveys using an ROV to identify if any objects are present before removing them.

6.2.8 Transportation by pipeline –routine

6.2.8.1 Presence of pipelay barge, trench vessel, rock dump vessel and associated tugs and support vessels

ENVIRONMENTAL ASPECT
Loss of access to fishing grounds; Interaction with other users of the sea

UK ENVIRONMENTAL REGULATORY CONTROL
- Petroleum Act 1998
- Pipeline Safety Regulations 1996
- Coast Protection Act 1949
- Notices to Mariners (M Notices) of navigation warning
- DETR Merchant Shipping Regulations

MITIGATION MEASURES
An operator may appoint a fisheries liaison officer to undertake consultation with fishermen. Other consultations may be carried out with any other parties affected by the activity. By law, an operator consults and notifies, during the preparation of an environmental statement, fishermen and other interested parties, including Ministry of Defence, The Archaeological Diving Unit (St. Andrews), British Telecommunications and Nature Conservation Organisations. This ensures that there is no interference other users of the sea.

6.2.8.2 Mobilisation of vessels

ENVIRONMENTAL ASPECT
Ballasting, or cleaning of, and discharge of dirty ballast or cleaning water from bunkerfuel tanks, disposal of oil residues, overboard discharge of oily water that has accumulated in machinery spaces – including pump rooms, whilst in port and the routine discharge at sea of oily bilge water; Exhaust emissions to air

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78
- No legislation controlling the introduction of non-native species into UK waters
- IMO Guidelines for the control and management of ship's ballast water to minimise the transfer of harmful aquatic organisms and pathogens
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Prohibition of oily discharges inside the 3nm limit
- Ships delivered before 6/7/93 – discharges are prohibited unless vessel is on a voyage, is 12 nm from land and the oil content is less than 100ppm
- Modern ships – discharges are prohibited unless vessel is under voyage and the oil content is less than 15ppm
- Vessels greater than 400 gross registered tonnes must have an oil/water separator, oil sludge tanks, a Shipboard Oil Pollution Emergency Plan, a UK Oil Pollution Prevention Certificate and an Oil Record book

MITIGATION MEASURES
The vessels, laying the pipeline, are under continual operation in the North East Atlantic and thus the risk of introducing non-native species should be zero. For all other forms of mitigation see 6.2.4.2.

6.2.8.3 Pre sweep dredging

ENVIRONMENTAL ASPECT
Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL
- Pipeline Works Authorisation (PWA) Consent to deposit materials on the seabed
- Petroleum and Submarine Pipelines Act 1975 and Authority required under Food and Environment Protection Act 1985
- Notices to Mariners (M Notices) of navigation warning

MITIGATION MEASURES
The only mitigation against dredging is to engineer-out its requirement in the first place. In certain circumstances it will be unavoidable. Environmental concern over dredging can be put into perspective when comparing pipeline dredging to the dredging industry that collects sea bed materials for aggregates.

6.2.8.4 *Anchoring operations for pip-lay barge*

ENVIRONMENTAL ASPECT
Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL

- Notices to Mariners (M Notices) of navigation warning

MITIGATION MEASURES
Depending on type of barge being deployed, anchor studies may be undertaken to determine an appropriate anchoring system suitable for seabed soils. This is used to prepare anchor-handling procedures. Safe distances from existing pipelines and other pipelines are established. Digital Global Positioning System may be used to monitor facilities position during anchoring operations. By law, an operator consults and notifies, during the preparation of an environmental statement, fishermen and other interested parties, including Ministry of Defence, The Archaeological Diving Unit (St. Andrews), British Telecommunications and Nature Conservation Organisations. This ensures that there is no interference with ordnance dumpsites, wreck sites, power cables, pipeline routes and other wells.

6.2.8.5 *Pipeline positioning on seabed and resultant presence*

ENVIRONMENTAL ASPECT
Physically covering parts of the seabed and providing a new substratum; Potential loss of area available for fishing; Potential for damage or loss to fishing gear or vessel immobilisation caused by entanglement on pipeline infrastructure; Potential loss of spawning grounds; Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL

- Authority required under Food and Environment Protection Act 1985
- Pipeline Safety Regulations 1996
- Coast Protection Act 1949
- Notices to Mariners (M Notices) of navigation warning

MITIGATION MEASURES
Consultations are undertaken as detailed in 6.2.8.1 & 6.2.8.4 to minimise environmental impact. The position of a pipeline is notified to the Naval Hydrographer and marked accordingly on Admiralty charts. Operators send information on pipeline routes to UKOOA. UKOOA and the UK Seafish Industry Authority have developed a seabed information service to avoid the risk of any accidents. The service provides information on any seabed obstructions, including: pipelines, flowlines and cable; and sea-surface facilities, including: fixed structures of any kind, mobile rigs and drill ships, floating production systems, and seismic survey operational plans.

6.2.8.6 *Trenching and backfilling*

ENVIRONMENTAL ASPECT
Seabed disturbance; Increased turbidity

UK ENVIRONMENTAL REGULATORY CONTROL

- Authority required under Food and Environment Protection Act 1985
- Pipeline Safety Regulations 1996

MITIGATION MEASURES
The only mitigation against trenching and backfilling is to engineer-out its requirement in the first place.

6.2.8.7 *Rockdumping*

ENVIRONMENTAL ASPECT
Seabed disturbance; Rock physically covering parts of the seabed and providing a new substratum; Potential loss of area available for fishing; Potential loss of spawning grounds; Generation of high frequency noise

UK ENVIRONMENTAL REGULATORY CONTROL

- Pipeline Works Authorisation (PWA) Consent to deposit materials on the seabed
- Petroleum Act 1998 and Authority required under Food and Environment Protection Act 1985
- Pipeline Safety Regulations 1996

MITIGATION MEASURES
Operators develop a rock-dumping procedure that ensures compliance with consent conditions under the PWA to minimise environmental impact. The use of a fall pipe on the rock dump vessel and a pre-dump survey minimises unnecessary dumping. Operators may also use Remotely Operated Vehicles (ROVs) to supervise operations.

6.2.8.8 Concrete mattress installation

ENVIRONMENTAL ASPECT
Seabed disturbance; Potential loss of area available for fishing; Potential loss of spawning grounds

UK ENVIRONMENTAL REGULATORY CONTROL
- Pipeline Works Authorisation (PWA) Consent to deposit materials on the seabed
- Petroleum Act 1998 and Authority required under Food and Environment Protection Act 1985

MITIGATION MEASURES
Operators develop a concrete mattress installation procedure that ensures compliance with consent conditions under the PWA to minimise environmental impact. A considerable number of these can be used for a field development requiring removal during the decommissioning phase.

6.2.8.9 Risers and spool pieces installation and tie in operations

ENVIRONMENTAL ASPECT
Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL
- Pipeline Safety Regulations 1996

MITIGATION MEASURES
Digital GPS positioning may be used to improve the likelihood of a successful tie-in and thereby reduce the possibility of the need to re-position.

6.2.8.10 Disposal of waste collected during pigging

ENVIRONMENTAL ASPECT
Marine discharge - Smothering and/or contamination of the seabed and water column

UK ENVIRONMENTAL REGULATORY CONTROL
- Pipeline Safety Regulations 1996

MITIGATION MEASURES
Pipe-joints are blasted internally to remove any scale. The discharge may be run through a strainer to collect contents for onshore disposal before being directed to the sea. *See 6.2.6.7.*

6.2.8.11 Flooding, hydrotesting and dewatering operations

ENVIRONMENTAL ASPECT
Marine discharge - Potential contamination of the seabed and water column

UK ENVIRONMENTAL REGULATORY CONTROL
- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)
- Chemical discharges are voluntarily monitored and recorded in SCOPEC database.
- Petroleum Act 1998
- Pipeline Safety Regulations 1996

MITIGATION MEASURES
Chemicals used have to be approved either by SERAD or MAFF, and categorised under HOCNS. A Pipeline Works Authorisation will detail a rate of discharge. These conditions collectively are designed to minimise the environmental impact of any discharges.

6.2.8.12 Displacement of nitrogen conditioning gas and burning of natural gas

ENVIRONMENTAL ASPECT
Atmospheric emissions (CO_2, NO_2, SO_2 and particulates)

UK ENVIRONMENTAL REGULATORY CONTROL

- Pipeline Safety Regulations 1996

MITIGATION MEASURES

Monitoring of vent gas composition ensures that the pipeline may be shut as soon as a given concentration of natural gas is detected. For efficient flaring see 6.2.4.11. If dewatering may be achieved using natural gas then flaring is not necessary.

6.2.8.13 Sacrificial anodes and antifoulant coating

ENVIRONMENTAL ASPECT

Heavy metal emissions and release of contaminants to sea

UK ENVIRONMENTAL REGULATORY CONTROL

- No legislative controls

MITIGATION MEASURES

An operator may ensure that there is no unnecessary over capacity of anodes used.

6.2.8.14 Inspection, maintenance and repair

ENVIRONMENTAL ASPECT

Seabed disturbance; Bilge water discharge and atmospheric emissions from vessels

UK ENVIRONMENTAL REGULATORY CONTROL

- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78
- Pipeline Safety Regulations 1996
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Water Resources Act 1991
- Control of Pollution Act 1974 and Amendments and Regulations
- Coast Protection Act 1949
- Notices to Mariners (M Notices) of navigation warning
- Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999

MITIGATION MEASURES

Exhaust emissions from operation of vessels are inevitable. Zero emissions are impossible even with electrical power or the use of clean fuels such as hydrogen. Equipment with zero emissions produce a pollution displacement effect i.e. from the equipment to fixed power generating plants or industrial plants. Local pollutants will be reduced, but life-cycle analysis will show that resource use or global impacts will remain. See 6.2.4.2.

Consultations with affected parties are carried out to avoid any interaction with other users of the sea.

If the pipeline work has been contracted out then an operator may interface with the contractors' management system to ensure that their operations comply with the law and with the operator's environmental policy.

6.2.9 *Transportation by shuttle tanker - routine*

6.2.9.1 *Power generation*

ENVIRONMENTAL ASPECT
Atmospheric Emissions (CO_2, NO_x, SO_x, PM_{10})

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78

MITIGATION MEASURES
Diesel engines are highly efficient combustion engines and do not produce a significant amount of evaporative emissions. The fuel is completely converted to CO_2 and H_2O, CO and HCs are quite low. Nitrogen oxides and particulates are a problem for diesel. Most of the sulphur in diesel fuel is converted into SO_2, and emitted as gas. Optimisation of energy usage and increased combustion efficiency would also reduce nitrogen oxides and SO_2. Nitrogen oxides (NO_X) may be reduced by flue gas "denoxing" using catalysts or injecting steam or water into the combustion chamber. See 6.2.4.2.

6.2.9.2 *Ballast and bilge water discharges*

ENVIRONMENTAL ASPECT
Oil and chemical discharge

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislation controlling the introduction of non-native species into UK waters
- IMO Guidelines for the control and management of ship's ballast water to minimise the transfer of harmful aquatic organisms and pathogens
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Prohibition of oily discharges inside the 3nm limit
- All discharges are prohibited unless the tanker is under voyage, more than 50 miles from land and oil content in discharge is less than 30 litres per mile
- Vessels greater than 400 gross registered tons must have an oil filtering equipment, oil sludge tanks, a Shipboard Oil Pollution Emergency Plan, a UK Oil Pollution Prevention Certificate and an Oil Record book

MITIGATION MEASURES
Shuttle tankers by their very name, literally shuttle to and from a field development in the North East Atlantic and thus the risk of introducing non-native species should be zero. They are not to be confused with international tankers travelling long distances that traverse very different biotopes. See 6.2.2.1. The segregated ballast tank system has to be completely separated from the cargo oil and fuel oil system. There is a provision for the emergency discharge of segregated ballast by means of a connection to a cargo pump through a portable spool piece. In such cases a non-return valve has to be fitted to the segregated ballast connections to prevent the passage of oil to the segregated ballast tanks. Tankers operating a Clean Ballast Tank system, under Regulation 20 of The Merchant Shipping (Prevention of Oil Pollution) Regulations 1996, must have a 'common system' in which the pumping and piping arrangements are common with the cargo system an the ballast tanks are isolated from the cargo by two valve separation or, a 'separate independent system' in which the pumping and piping system is separate and independent from the cargo system and isolated from it by two valve separation.

6.2.9.3 *Loading and offloading oil*

ENVIRONMENTAL ASPECT
Venting of VOCs and potential for oil spillage

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
BP's Foinaven Phase 1 Development Environmental Assessment identified that offshore loading at the Petrojarl Foinaven and field shuttle tankers is the largest source of VOCs and CH_4 emissions to the atmosphere from the FPSO development. Loading rate is a critical parameter in determining emissions rates, other factors include tanker export design, crude oil temperature and inert gas HC concentration. There are two broad methods of offshore loading that have been carried out on the UKCS. Catenary moored buoys with floating hoses (CALMS) and other systems (non-CALMS). CALMS are no longer used over the UKCS. There are several emissions control methods that are available for truck loading which could be applied to marine loading. These can be characterised as recovery systems or combustion systems, or a combination of the two: compression-absorption; compression-cooling; cryogenic refrigeration; adsorption systems (adsorption-absorption, or absorption-adsorption-absorption); vapour combustor systems (open or enclosed flare, or incinerator); vessel mounted systems (Hill, 1990). Vos Process Systems (Netherlands) market a vapour recovery system that utilises an American technique based on the principle of adsorption on to active carbon. It is designed to prevent the

escape of VOCs into the atmosphere. BP's Foinaven Phase 1 Development Environmental Assessment recorded that offshore loading emissions recovery systems had only recently been developed (at the time of writing) and were not expected to be commercially available until 1997 (BP, 1995).

The Institute of Petroleum's database on crude oil loss, identified that the mean loss of oil from crude oil shipping was 0.19% per voyage (Institute of Petroleum, 1997).

Historical risk assessments to identify trends in spill frequency from causes are undertaken to provide an indication of the areas of potential highest spill risk for any Development activity. Historical data for spills from FPSO's starts 1992. For loading using non-CALMS to shuttle tankers the data commences in 1976. See 6.2.5.3 for oil spill contingency planning.

6.2.9.4 Waste Disposal

ENVIRONMENTAL ASPECT
Garbage and sewage wastes. In a 1995 survey of vessels and their wastes, carried out by Environment Resource and Technology, the following for shuttle (coastal) tankers was recorded:

Size: 500 – 1,600 dwt tonnes
Maximum number of people at Sea: 4-15
Duration at sea: 1-2 days
Deck and domestic waste: 1.5-2kg/day/person
Special waste: -
Scrap metal: -
Black water/grey water: 150-250 dm^3/day/person (sewage macerators common)
Treatment Equipment: It was not uncommon for: oil and garbage incinerators; sewage macerators or full treatment plant; and garbage compactors, to be present.

comparatively the following for very large crude carriers (VLCCs) was recorded:

Size: 100,000 – 350,000 dwt tonnes
Maximum number of people at Sea: 35-40
Duration at sea: 28 days
Deck and domestic waste: 1.5-2kg/day/person
Special waste: -
Scrap metal: -
Black water/grey water: 150-250 dm^3/day/person (sewage macerators common)
Treatment Equipment: It was not uncommon for: oil and garbage incinerators; sewage macerators or full treatment plant; and garbage compactors, to be present.

UK ENVIRONMENTAL REGULATORY CONTROL
- Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1998
- Merchant Shipping and Maritime Security Act 1997; Merchant Shipping (Carriage of Dangerous Goods at Sea) Regulations 1995

MITIGATION MEASURES
See 6.2.4.16.

6.2.10 Transportation by pipeline - accidents

6.2.10.1 Loss of containment

ENVIRONMENTAL ASPECT
Release of produced gas and methanol due to pipeline fracture; Release of produced oil and liquid gas condensate due to pipeline fracture

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997 Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Food and Environment Protection Act 1985
- Water Resources Act 1991, Control of Pollution Act 1974
- Petroleum Act 1998
- Pipeline Safety Regulations 1996
- Coast Protection Act 1949
- Notices to Mariners (M Notices) of navigation warning

MITIGATION MEASURES
Large volume of oil released from pipeline leaks will be detected through changes in throughflow and consequently halted by ceasing flow and repairing the fracture. Chronic leaks, small and continual, increasing the volume discharged over time are a problem. Polyconsult Servizi SRL of Fano, Italy have developed an acoustic method of recording transient events in kilometres of pipeline that detects losses. These events can be detected through changes in pressure and temperature. There are a variety of requirements of the Pipelines Inspectorate to minimise the risk of pipeline fracture these include burying and trenching the pipeline. If it is not trenched and buried then it has to be demonstrated that the pipeline: has sufficient stability, will not be damaged by trawling gear; and, is of at least 16 inches diameter.

6.2.10.2 Mishandling of materials such as plastic sheeting, bags, containers, oil drums, lengths of wire and heavy objects

ENVIRONMENTAL ASPECT
Dropped objects – persistent waste released to sea; Overboard spillage of hydraulic fluid or chemicals

UK ENVIRONMENTAL REGULATORY CONTROL
- Food and Environment Protection Act 1985
- Offshore Installations (Safety Case) Regulations 1992
- Pipeline Safety Regulations 1996
- Petroleum Operations Notice 2

MITIGATION MEASURES
Development of a waste management plan; If a vessel has a plan in place already HSE training and management can improve handling practices on decks and thereby prevent the accidental dropping of objects overboard. It would be an infringement of the Food and Environmental Protection Act to leave dropped objects on the seabed. Operators may carryout post decommissioning surveys using an ROV to identify if any objects are present before removing them. An example of use of ROVs may be found in Amerada Hess's Durward and Dauntless Surface and Subsea Facilities Decommissioning Plan at http://www.hess.com/worldwide/europe/dur_daunt.html.

6.2.10.3 Vessel collision with pipeline

ENVIRONMENTAL ASPECT
Loss of fuel, cargo, and chemicals

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- Food and Environment Protection Act 1985

MITIGATION MEASURES

The position of a pipeline is notified to the Naval Hydrographer and marked accordingly on Admiralty charts. Operators send information on pipeline routes to UKOOA. UKOOA and the UK Seafish Industry Authority have developed a seabed information service to avoid the risk of any accidents. The service provides information on any seabed obstructions, including: pipelines, flowlines and cable; and sea-surface facilities, including: fixed structures of any kind, mobile rigs and drill ships, floating production systems, and seismic survey operational plans. For chemical and oil spill clean-up see 6.2.5.3. As demersal fishing intensity is not uniform across the North East Atlantic, quantitative risks assessments may also be carried out, using fishing data, to assess the probability of a single trawl crossing any unit length of pipeline.

6.2.11 Transportation by shuttle tanker – accidents

6.2.11.1 Collision, grounding, foundering and fire/explosion

ENVIRONMENTAL ASPECT
Release of oil products into atmosphere, land and sea

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- Food and Environment Protection Act 1985

MITIGATION MEASURES

When looking at the data with respect to the causes of major oil tanker accidents, one conclusion is evident, human error is the major cause. It is public perception that oil spillage from a tanker is the responsibility of the operator from whom it was collected. This is true for tankers under international voyage. The oil is transported under contract, and therefore any environmental damage becomes the liability of the contractor. However shuttle (coastal) tankers are an integral part of FPSO field design and thus are the responsibility of the operator. Tanker design is an important element in determining the outflow of oil after an accident. The Marine Environmental Protection Committee of the International Maritime Organisation agreed new oil tanker design standards (double hull and mid-deck) that became international law on 6 July 1993 under 13F of Annex I of the MARPOL Convention. No mid-deck tanker has ever been built or ordered as such vessels would be denied entry into US ports. The US Oil Pollution Act 1990 has not changed to accept mid-deck tankers and other designs, only double hulled.

6.2.11.2 Venting

ENVIRONMENTAL ASPECT
Release of oil products into atmosphere

UK ENVIRONMENTAL REGULATORY CONTROL
- No legislative controls
- (Recommendations on reducing the impact of VOCs in Montreal Protocol.)

MITIGATION MEASURES
When transportation by tankers applies the contribution of oil degassing to the overall VOC emissions can reach a value as high as 90% of total tanker emissions (Oldervick O & Lerstad A, 1991).

6.2.12 Decommissioning - routine

6.2.12.1 Mobilisation and working and de-mobilisation of vessels at site

ENVIRONMENTAL ASPECT
Exhaust emissions; Loss of access to potential fish stocks

UK ENVIRONMENTAL REGULATORY CONTROL
Annex VI of MARPOL 73/78 Regulations for the Prevention of Air Pollution from Ships

MITIGATION MEASURES
An operator may appoint a fisheries liaison officer to undertake consultation with fishermen. Other consultations may be carried out with any other parties affected by the activity.

Diesel engines are highly efficient combustion engines and do not produce a significant amount of evaporative emissions. The fuel is completely converted to CO_2 and H_2O, CO and HCs are quite low. Nitrogen oxides and particulates are a problem for diesel. Most of the sulphur in diesel fuel is converted into SO_2, and emitted as gas. Optimisation of energy usage and increased combustion efficiency would also reduce nitrogen oxides and SO_2. Nitrogen oxides (NO_X) may be reduced by flue gas "denoxing" using catalysts or injecting steam or water into the combustion chamber. Emissions generated are monitored and the quantity discharged is recorded and reported to UKOOA under the Environmental Emissions Monitoring System. See 6.2.4.2.

6.2.12.2 Pipeline flushing

ENVIRONMENTAL ASPECT
Discharge of chemicals to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- Voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF)
- Chemical discharges are voluntarily monitored and recorded in SCOPEC database

MITIGATION MEASURES
Chemicals used have to be approved either by SERAD or MAFF, and categorised under HOCNS. These conditions collectively are designed to minimise the environmental impact of any discharges.

6.2.12.3 Concrete mattress placement and/or sandbags over cut ends of pipelines

ENVIRONMENTAL ASPECT
Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL
- Pipeline Works Authorisation (PWA) Consent to deposit materials on the seabed
- Petroleum Act 1998 and Authority required under Food and Environment Protection Act 1985

MITIGATION MEASURES
Operators may develop a concrete mattress installation procedure that minimise environmental impact under their abandonment programme and environmental management system

6.2.12.4 Dismantling Topsides, Jacket and Footings

ENVIRONMENTAL ASPECT
Seabed disturbance; Sound and shock waves generated by explosions

UK ENVIRONMENTAL REGULATORY CONTROL
- Petroleum Act 1998
- The Coast Protection Act 1949
- The Environmental Protection Act 1990
- Food and Environment Protection Act 1985
- Radioactive Substances Act 1993
- Health and Safety at Work etc. Act 1974

- Prevention of Oil Pollution Act 1971
- (OSPAR Decision 98/3 (Dismantling): International Maritime Organisation Regulations 1989 (Disposal))

MITIGATION MEASURES
Decommissioning studies are undertaken to assess the potential environmental effects of possible options. This is part of the planning for decommissioning process that the DTI's Decommissioning Unit in Aberdeen offers advice on. The Unit ensures that the technical, safety, environmental and economic issues have been carefully studied and presented as a decommissioning programme that is open to public debate and review. Consultation with experts, as in the preparation of an Environmental Statement, is conducted to minimise environmental liability.

6.2.12.5 Mechanically cutting off well casing below the seabed

ENVIRONMENTAL ASPECT
Metal emissions

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
Procedures of this nature serve in themselves to ensure no future environmental impact and may be conducted under an Operator's environmental management system to minimise any impact to the environment.

UKOOA's Guidelines for the Suspension and Abandonment of Wells recommend the use of two extensively tested barriers down hole. These are permanent barriers which seal the well by 'plugging'. The casing strings are removed to a depth of 3 m (10 ft) below the seabed. All other obstructions are removed and the well's method of clearance is discussed with all the relevant fishing organisations in the area. Procedures of this nature serve in themselves to ensure no future environmental impact and may be conducted under an Operator's environmental management system to minimise any impact to the environment.

UKOOA and the UK Seafish Industry Authority have developed a seabed information service to avoid the risk of any accidents. The service provides information on any seabed obstructions and sea-surface facilities.

6.2.12.6 Retrieval of casing

ENVIRONMENTAL ASPECT
Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
Procedures of this nature serve in themselves to ensure no future environmental impact and may be conducted under an Operator's environmental management system to minimise any impact to the environment.

6.2.12.7 Mechanically cutting through piles below the seabed

ENVIRONMENTAL ASPECT
Metal emissions

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
Procedures of this nature serve in themselves to ensure no future environmental impact and may be conducted under an Operator's environmental management system to minimise any impact to the environment.

6.2.12.8 Transporting all recovered material to shore

ENVIRONMENTAL ASPECT
Exhaust emissions

UK ENVIRONMENTAL REGULATORY CONTROL
- Exhaust emissions pending legislation under Annex VI of MARPOL 73/78
- Petroleum Act 1998
- Merchant Shipping (Prevention of Oil Pollution) Regulations 1996
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) Regulations 1996

MITIGATION MEASURES

Diesel engines are highly efficient combustion engines and do not produce a significant amount of evaporative emissions. The fuel is completely converted to CO_2 and H_2O, CO and HCs are quite low. Nitrogen oxides and particulates are a problem for diesel. Most of the sulphur in diesel fuel is converted into SO_2, and emitted as gas. Optimisation of energy usage and increased combustion efficiency would also reduce nitrogen oxides and SO_2. Nitrogen oxides (NO_X) may be reduced by flue gas "denoxing" using catalysts or injecting steam or water into the combustion chamber.

6.2.12.9 Dismantling structures at the onshore receiving site (mechanically cutting and removal of biofouling material)

ENVIRONMENTAL ASPECT

Solid Waste (anodes, asbestos, biocides, chlorofluorocarbons; fire extinguishers; accumulators; plastic; hydrocarbons; mineral fibre; marine growth; mercury, nickel cadmium batteries; fire protection materials; polychlorinated biphenyls, pyrophoric materials; radioactive materials; steel and, sewage); Gaseous emissions; Contaminated drainage; Noise; Nuisance; Ground vibration; Dust; Odour; Light

UK ENVIRONMENTAL REGULATORY CONTROL

- Environmental Protection Act 1990; Environmental Protection (Duty of Care) Regulations 1991; Environment Act 1995; Special Waste Regulations 1996; Waste Management Regulations 1996; Controlled Waste Regulations 1992

MITIGATION MEASURES

Dismantling is contracted to a decommissioning specialist, who are aware of the environmental reasons for decommissioning and as such have in place an environmental management system to ensure that the procedures that they adopt comply with controls implemented by the Environment Agency or the Scottish Environmental Protection Agency.

Radioactively contaminated materials (LSA found either in oily sludge or in scale on equipment) are removed, treated and stored in special containers before being disposed of in a licensed landfill facility.

Mercury in contaminated waste may be recycled and refined or disposed of in a licensed landfill facility.

Asbestos insulation products and asbestos cement board are classified as Special Wastes and are thus transport and disposal must be licensed. The economic solution currently is to dispose of asbestos in a licensed landfill facility.

Marine growth on a structure generates an obnoxious smell when it starts to biodegrade. Antifoulant paints also can contaminate it. It is removed using a high pressure, low volume, water jet. Uncontaminated marine growth may be dried, processed and used as a fertiliser, or disposed of in landfill. Contaminated marine growth is either sent to landfill or incinerated.

6.2.12.10 Recycling of materials

ENVIRONMENTAL ASPECT

Atmospheric emissions; Chemical discharges into inland waterways and coastal waters

UK ENVIRONMENTAL REGULATORY CONTROL

- Environmental Protection Act 1990; Environmental Protection (Duty of Care) Regulations 1991; Environment Act 1995; Special Waste Regulations 1996; Waste Management Regulations 1996; Controlled Waste Regulations 1992;
- Integrated Pollution Control

MITIGATION MEASURES

Procedures of this nature serve in themselves to ensure no future environmental impact and may be conducted under an Operator's environmental management system to minimise any impact to the environment.

Depending upon the level of fatigue the jackets or topsides have experienced under the field life, platforms may be removed, refurbished and re-installed elsewhere. Equipment is being sold including, in particular, diesel engines, compressors, generators and cranes from platforms.

6.2.12.11 Post decommissioning seabed clearance by trawling

ENVIRONMENTAL ASPECT

Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL

No legislative controls

MITIGATION MEASURES

Procedures of this nature serve in themselves to ensure no future environmental impact and may be conducted under an Operator's environmental management system to minimise any impact to the environment. Any remains that are left in place may have to be monitored by the operator at regular intervals. A suitable monitoring programme with the DTI for this residual environmental liability in perpetuity has to be agreed.

6.2.12.12 Landfill disposal

ENVIRONMENTAL ASPECT
Solid Wastes; Drill Cuttings; Atmospheric emissions (Methane)

UK ENVIRONMENTAL REGULATORY CONTROL
- Licence for landfill disposal

MITIGATION MEASURES
Drill cuttings collection and treatment technologies before landfill disposal are detailed in 6.2.4.5. However burial of wastes does not always bury the problem and attention needs to be directed toward the potential escape of hazardous gases and liquids. These are produced by micro-organisms. Good landfill design and operation will ensure that environmental liabilities are minimised. Thus, any waste for burial must be directed toward a licensed landfill operator.

6.2.12.13 Landfarming

ENVIRONMENTAL ASPECT
Cuttings thinly spread over soil surface and biodegrade; Odour

UK ENVIRONMENTAL REGULATORY CONTROL
No legislative controls

MITIGATION MEASURES
Landfarming is by its very nature a mitigation measure. See 6.2.4.5.

6.2.13 Decommissioning - accidents

6.2.13.1 Mishandling of materials such as plastic sheeting, bags, containers, oil drums, chemical containers, pipeline, lengths of wire and heavy objects

ENVIRONMENTAL ASPECT
Oil, chemicals and persistent waste released to sea

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997 Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Food and Environment Protection Act 1985
- Water Resources Act 1991, Control of Pollution Act 1974
- Petroleum Operations Notice 1
- Petroleum Operations Notice 2

MITIGATION MEASURES
Development of a waste management plan; If a vessel has a plan in place already HSE training and management can improve handling practices on decks and thereby prevent the accidental dropping of objects overboard. It would be an infringement of the Food and Environmental Protection Act to leave dropped objects on the seabed. Operators may carryout post decommissioning surveys using an ROV to identify if any objects are present before removing them.

6.2.13.2 Leakage from abandoned wells

ENVIRONMENTAL ASPECT
Hydrocarbons enter local environment

UK ENVIRONMENTAL REGULATORY CONTROL
- The Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997 Regulation 5(2) and Regulation 4(1)(c) of The Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Food and Environment Protection Act 1985
- Water Resources Act 1991, Control of Pollution Act 1974
- Petroleum Operations Notice 1

MITIGATION MEASURES
See 6.2.4.20 & 6.2.4.21.

6.2.13.3 Failure of structural integrity during decommissioning

ENVIRONMENTAL ASPECT
Falling debris; Hydrocarbon or chemical discharge to land, sea or air; Seabed disturbance

UK ENVIRONMENTAL REGULATORY CONTROL
There is a wide range of environmental legislation that may be relevant and lead to a prosecution in the event of an accident. The legislation is dependent on the environmental aspect that occurs and where it occurs.
- Health and Safety at Work etc. Act 1974
- Petroleum Act 1998
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- Model Clause 23(8) of Schedule 4 of the Petroleum (Production) (Seaward Areas) Regulations 1988 No 1213
- Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998
- Prevention of Oil Pollution Act 1971 and 1986 (as amended by the Merchant Shipping Act 1995)
- Food and Environment Protection Act 1985
- Water Resources Act 1991, Control of Pollution Act 1974
- Petroleum Operations Notice 1

MITIGATION MEASURES

The Offshore Installations (Safety Case) Regulations 1992, under the Health and Safety at Work etc Act 1974, require acceptance by the Health and Safety Executive (HSE) of a safety case for the decommissioning of an offshore installation. This is submitted to the HSE at least 6 months before the commencement of decommissioning operations. Consequently an acceptance of a safety case by the HSE means that the UK Government is satisfied that all risks of major accidents have been identified, and that measures have been and will be taken to reduce risks to persons affected by these hazards to as low as reasonably practicable. Regulation 10 of the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 requires the safe decommissioning and dismantlement of an installation with respect to its integrity; and the Pipelines Safety Regulations 1996 contain requirements that pipelines are decommissioned safely either by dismantlement and removal or by being left in a safe condition (Department of Trade & Industry, 1999b).

6.2.14 Key Environmental Aspects

6.2.14.1 Routine Environmental Aspects

Routine Environmental Aspects	RESERVOIR WASTE MANAGEMENT	SEISMIC	DRILLING	PRODUCTION	PIPELINE TRANSPORTATION	TANKER TRANSPORTATION	DECOMMISSIONING
Solid Material							
▪ Presence	■		■	■	■		
▪ Discharge of Solid Material			■	■	■		■
▪ Heavy Metals			■	■	■		■
▪ Seabed Disturbance		■	■	■	■		■
▪ Persistent Waste to Sea or Land		■	■	■	■	■	■
▪ Low Specific Activity Scale				■			■
▪ Injection of Waste into Formation	■						
Energy							
• Disturbance	■	■	■	■	■	■	■
• Sound in the Water		■	■	■	■	■	■
• Sound in the Air		■	■	■	■	■	■
Liquid							
• Hydrocarbons released to Sea	■	■	■	■	■	■	■
• Oil-based Muds			■	■			■
• Water-based Muds			■	■			
• Synthetic-based Muds			■	■			
• Introduction of Foreign Species from Ballasting		■	■	■	■	■	■
• Chemical Discharges		■	■	■	■		■
• Sewage and other Facility Wastes		■	■	■		■	■
• Brines			■	■			
• Injection of Waste into Formation	■			■			
• Heated Water			■	■			
Atmospheric Emissions							
• CO_2	■	■	■	■	■	■	■
• CO	■	■	■	■	■	■	■
• Oxides of nitrogen	■	■	■	■	■	■	■
• SO_2	■	■	■	■	■	■	■
• CH_4			■	■	■		
• CFCs/CBCs/other Halons			■	■			
• VOCs			■	■		■	
• H_2S			■	■			
• Particulates (PM_{10})	■	■	■	■	■	■	■
• Odour			■				■
Society							
• Social Interaction	■	■	■	■	■	■	■

6.2.14.2 Accidental Environmental Aspects

Accidental Environmental Aspects	RESERVOIR MANAGEMENT	SEISMIC	DRILLING	PRODUCTION	PIPELINE TRANSPORTATION	TANKER TRANSPORTATION	DECOMMISSIONING
Solid Material							
• Presence							
• Discharge of Solid Material			■				
• Heavy Metals							
• Seabed Disturbance							■
• Persistent Waste to Sea or Land			■	■			■
• Injection of Waste into Formation	■						
Energy							
• Disturbance							
• Sound in Water		■					■
• Sound in Air		■					
Liquid Discharges							
• Hydrocarbons released to Sea	■	■	■	■	■	■	■
• Oil-based Muds							
• Water-based Muds							
• Synthetic-based Muds							
• Introduction of Foreign Species from Ballasting							
• Chemical Discharges	■		■	■	■		
• Sewage and other Facility Wastes							
• Brines							
• Injection of Waste into Formation	■			■			
• Heated Water							
Atmospheric Emissions							
• CO_2	■		■	■			
• CO							
• Oxides of nitrogen							
• SO_2							
• CH_4			■	■	■	■	
• CFCs/CBCs/other Halons			■	■			
• VOCs			■	■		■	
• H_2S			■	■			
• Particulates (PM_{10})			■	■			
• Odour			■	■			
Society							
• Social Interaction	■	■	■	■	■	■	■

6.2.15 Environmental Risk Mitigation Costs

Development Phase	Environmental Expenditure	Location	Economic Data UK £2000	Source
Licensing				
Environmental Appraisal	PON 15 Preparations	Local	5000 - 10000/well	*Personal Communication* ARCO British's Environment Department 26 January 2000
	Oil Spill Plans	Local, National & Transboundary	2000 - 5000/well	*Personal Communication* ARCO British's Environment Department 26 January 2000
	British Oil Spill Contingency Association Company Membership	National	40,000	*Personal Communication* ARCO British's Environment Department 26 January 2000
	Baseline Environmental Site Survey	Local	80,000	*Personal Communication* ARCO British's Environment Department 26 January 2000
	Risk Assessment	Local, National & International	2000/facility	*Personal Communication* ARCO British's Environment Department 26 January 2000
	Preparation of an Environmental Statement	Local	81,100 - The DTI estimated that a full environmental statement for a major development or pipeline in a relatively accessible area ,i.e. near the coast or in the shallow waters of the North Sea or Irish Sea, could cost up to £81,100. An exploration well was estimated cost up to £27,000. For wells or developments in deep-water areas it was calculated that there could be a doubling or trebling of these figures. These costs are considered to be insignificant by the DTI when compared to total project budgets, which vary from £10 million for single exploration wells to several million pounds for a full development	Department of Trade and Industry, 1998c
Management	Environmental Management System ISO 14001	Local	10,000 - £100,000	*Personal Communication* BPAmoco, 1999
Monitoring	Environmental Monitoring	Local	30,000/year	*Personal Communication* ARCO British's Environment Department 26 January 2000
Reservoir				
Controlling the amount of oil in produced water prior to injection	Hydrocyclones - reduce oil in water content down to 15-35 ppm (throughput: 100-2,500 bwpd)	Local	0.01/bwpd	Orsulik, 1997
	5 Centrifuge System - reduce oil in water content down to 5-20 ppm	Local	Capex 625,000; Opex 16200/month	Environmental Resources Management, 2000
	Membrane Filtration (Diffusion barrier technology)- reduce oil in water content to <5ppm (throughput 70 bwpd; input oil-in-water >150 ppm)	Local	0.01-0.04/bbl of oil produced	Orsulik, 1997
	Hydrocyclone Downhole Oil/Water Separation Unit (discharge of produced water at surface eliminated); input: 300-800 ppm oil-in-water to formation	Local	61,800 - 171,600/unit; opex: 0.66 bwpd	Rudolph & Rueter, 2000
	Gravity Downhole Oil/Water Separation Unit (discharge of produced water at surface eliminated); input: <500 ppm oil-in-water to formation	Local	10,300 - 17,200/unit; opex: 0.66 bwpd	Rudolph & Rueter, 2000

Development Phase	Environmental Expenditure	Location	Economic Data UK £2000	Source
Seismic Surveying				
Precaution	Ramp up to, delay of, or cessation of firing air-gun array in the presence of vulnerable species (In the Reconnaissance phase of field development seismic data collection is contracted out to a companies including Fugro-Geoteam AS, Baker Hughes, PGS and Schlumberger Geco-Prakla. The contract between operator and contractor will therefore cover any environmental risk mitigation measures and thus become the responsibility of the contractor).	Local	3000 - 5000/ hr. Cost is estimated in the form of delay of data acquisition to the contractor. Purely voluntary measure and dependent upon identification of a marine mammal. Identification is prevented by increased wave heights, poor visibility, nightfall and whether animals surface within view of an observer. The cost to the operator is principally in the form of delay. Any delays would increase the cost of the survey. The cost of hiring a seismic vessel for a month runs between $3 million to $5 million. Delays are also caused by weather, thus further potential delay increases costs. The cost of mitigation technology, i.e. that which cuts out the high frequency output from a seismic pulse (Goold & Fish, 1998) or a further reduction of the horizontal propagation of sound pulse, by comparison to precautionary delays could be cost effective. Any delays would increase the cost of the survey.	International Association of Geo-engineering Contractors, 1998
Controlling emissions to air from power generation	Low Emission Diesel Combustion Units	Local	0.22-0.37/kg oxides of Nitrogen & 0.3-0.8/kg Sulphur dioxide emitted (economic data unclear)	The Swedish NGO Secretariat on Acid Rain, European Environmental Bureau (EEB), and European Federation for Transport and Environment (T&E), 2000
Controlling emissions to air from refueling	Emission control systems for refueling operations	Local	33k-660k (capex) - 26k-56k (opex) - he capital cost for emission control systems process vapour from the loading of 10,000 bbl/hour of gasoline. The annual operating costs process vapour from the loading of 10,000 bbl/hour of gasoline	Hill, 1990
	On-board vessel waste control systems	Local	no cost data identified	-
	Ballast Water and Bilge Water Control	National	CAPEX 30,000 per on-line Oil in Water Monitor; OPEX UK 900 per on-line Oil in Water Monitor (Monitor required for each outfall of water)	Personal Communication Steptech Instrument Services Limited, 27th March 2000
Dealing with accidental and abnormal events	Clean-up of oil spillage offshore (Streamer cables contain kerosene to aid buoyancy. Spillage occurs as a result of elasmobranchs biting and rupturing the cables)	Local	77-116/bbl of spilt oil recovered; Clean-up offshore using a boom system that surrounds a spillage and uses synthetic absorbent materials to improve efficiency of operation. Only able to use such equipment when conditions at sea are mild	Boben, 1996
	Interruption of Operations by Pressure Group	Local	3000 - 5000/ hr. Cost is estimated in the form of delay of data acquisition to the contractor.	International Association of Geo-engineering Contractors, 1998
	Loss of persistent waste to sea	Local, National & Transboundary	100 - 300/km of beach; Clean-up of beaches of floating material is dependent on the deposited wastes. This estimate includes equipment and transportation costs. Persistent waste that becomes flotsam and jetsam has to be cleared from beaches that are used by people for recreation. Litter squads (3 men) operated by Fife Council take 2-5 hours to clean 1 km of beach.	*Personal Communication* Daniels, 1999

Development Phase	*Environmental Expenditure*	*Location*	*Economic Data UK £2000*	*Source*
Drilling				
Controlling emissions to air from power generation	Dry Low Emission Combustion Technology for Gas Fueled Turbines	Local	537,460/turbine (capex); 230-307/Kg of NO_x reduced (opex); Dry Low Emission Combustion Technology for gas fueled turbines. As the primary function of equipment is to provide power, the environmental expenditure to comply with the new regulations will be the marginal cost of upgrading and any modifications to combustion	Moltv, 1997
Reducing the impact of drilling fluids	Low Toxicity Water-based Muds (using category E chemicals as far as possible)	Local	8.8 million/well	Veil et al., 1996
	Low Toxicity Synthetic-based Muds	Local	4.17 million/well	Veil et al., 1996
	Total Containment Technology	Local, National	300-400/te (transportation and disposal)	Personal Communication ExxonMobil, 2000
	Onshore Waste Oil Treatment	National	29/te; Average cost for recycling lubricating oil and producing virgin quality base oil using a patented process.	Interline Resources Corporation, 1998
Treatment and disposal of contaminated drilled formation cuttings	No offshore treatment of solids or liquids, transport to shore, onshore dewatering and onshore indirect thermal treatment of all solids	National	580/te	Environmental Resources Management, 2000
	Offshore water treatment and disposal, transport to shore, onshore indirect treatment of all solids	Local, National	332/te	
	Offshore water treatment and disposal, offshore disposal of solids >63 micro-m; transport to shore of solids <63 micro-m, onshore indirect thermal treatment of solids <60 micro-m	Local, National	256/te	
	No offshore treatment of solids or liquids, transport to shore, onshore dewatering, treatment and landfill disposal of all solids	National	150-200/te	
	No offshore treatment of solids or liquids, transport to shore, onshore dewatering and landfarming of all solids	National	130/te	
	Local re-injection of cuttings	Local	162.5 - 550/te (capex); 16.35/te (opex);	
	Transportation of cuttings to another site for re-injection into subsurface formation	National	162.5 - 550/te (capex); 29.4/te (opex);	
	Solids Treatment - Microemulsion	National	(No economic data)	
	Solids Treatment - Supercritical extraction (natural gas)	National	(No economic data)	
	Solids Treatment - Supercritical Extraction (CO2)	National	(No economic data)	
	Onshore incineration	National	160 - 190/te	Ness, 1999

Development Phase	*Environmental Expenditure*	*Location*	*Economic Data UK £2000*	*Source*
	Treatment required to eliminate toxic metals after incineration.	National	100 - 300/te	Davidson & Dusseault, 1997
	Landfill cost with potential liability treatments - Environmental problems abundant (e.g. limited space, gases created through the decomposition of wastes and membrane leakage leading to groundwater contamination)	National	180/te	Davidson & Dusseault, 1997
	Cost to process of SOBM cuttings and dispose of in landfill.		150 - 200/te	*Personal Communication* Recovery Systems in Lowestoft, 2000
	Landfarming - Environmental problems abundant (e.g. odour, blowing wastes, gases created through the decomposition of wastes and waste still classified as hazardous after 2 years of biodegradation		100/te	Davidson & Dusseault, 1997
	Salt Cavern Disposal - Viable only in areas where there exists a suitable evaporate formation (i.e. bedded salt or domal salt)		80 -100/te	Davidson & Dusseault, 1997
Cuttings washing water disposal	Onshore Disposal	Local, National	20/te; - Assuming a zero discharge policy in the area	Ferrari et al., 1997
Disposal of Brines	Onshore Disposal	Local	45-100/te; Onshore Disposal of Brines; Assuming a zero discharge policy in the area. In the UK brines are disposed of at sea.	Ferrari et al., 1997
Improving the efficiency of flare stack combustion	Efficient Flare Stack System	Local and Transboundary	Evergreen Burner - 34,320 (Capex); Flame Front Generator (FFG) 7,260; Flare boom: 66,000; HIRE: Evergreen Burners c/w FFG: 792/ day; Flare Booms: 495/ day; Set of 1200 SCFM air compressors: 1,056/ day; Personnel charges: 475/ day / per person	*Personal Communication* , Schlumberger 2000
Using infrastructure to reduce wasting fossil fuels	Export excess oil or gas instead of flaring	Local, National & Transboundary	If export facilities are available: Pipeline Tariff - £0.5/bbl - £1.5/bbl; Shuttle Tanker Tariff - £0.5/bbl - £1.5/bbl; Gas Pipeline Tariff - £0.25/Mscf. A new pipeline will be laid if no pipeline export facilities are available.	QUE$TOR OFFSHORE Version 7.1a
Environmental Monitoring	Ballast Water and Bilge Water Control	National	CAPEX 30,000 per on-line Oil in Water Monitor; OPEX 900 per on-line Oil in Water Monitor (Monitor required for each outfall of water, including water vapour)	Personal Communication Steptech Instrument Services Limited, 27th March 2000

Development Phase	*Environmental Expenditure*	*Location*	*Economic Data UK £2000*	*Source*
Waste Management	Non-hazardous Waste Control Systems - incineration	National	150 - 180/te; Incineration of non-hazardous waste	Ness, 1999
	Special Waste Control - plasma incineration	National	240/te; Plasma incineration of hazardous waste	Fosch, 1995
Dealing with accidental and abnormal events	Loss of persistent waste to sea - Clean-up of beaches of floating material is dependent on the deposited wastes. This estimate includes equipment and transportation costs. Persistent waste that becomes flotsam and jetsam has to be cleared from beaches that are used by people for recreation. Litter squads (3 men) operated by Fife Council take 2-5 hours to clean 1 km of beach.	Local, National & Transboundary	100 - 300/km of beach	*Personal Communication* Daniels, 1999
	Clean-up of Contaminated Land - Cleaning up contaminated land (brownfield land) and inland potable water sources is an expensive business. It involves physical cleanup costs, a fine and legal costs incurred following prosecution by the Environment Agency in England and Wales, and the Scottish Environmental Protection Agency in Scotland. This is an area where the variance in cost will be considerable as prosecutions increase and different clean up strategies are implemented.	Local	UK £80000 - £570000/acre; Costs for land contaminated by heavy industry	Bell, 1998; Davies, 1999
			US $67000/acre; Represents the cost of cleaning up soils contaminated with acid spillage	Shanley et al., 1999

Development Phase	Environmental Expenditure	Location	Economic Data UK £2000	Source
	Oil Spill Clean-up - Oil spill clean-up is big business. The important question is whether that business is good for the environment. Managing an oil spill is a matter of ecological trade-offs. Cleaning a rocky shoreline with high pressure heated water may remove the danger to animals walking the shoreline becoming covered in oil but it will kill the small, vastly numerous, animals inhabiting the rocky substrate. These are the greater part of the intertidal food web and are supporting the 'walking' animals (Katz, 1994). The general cost for oil spill clean-up is wasted because the recovery efficiency is poor. The cost of oil spill clean-up will depend upon the size of the spill and whether its fate is on- or offshore.	Local, National & Transboundary	77-116/bbl of spilt oil recovered; Offshore clean-up using mechanical containment and recovery	Boben, 1996
			39-77/bbl of spilt oil recovered; Offshore clean-up using dispersants	Boben, 1996
			15-39/ of oil burned; Offshore in-stu burning	Allen & Ferek, 1993
			1.5% - 2.3% Drop in Share Value Risk; Offshore Natural Dispersion (Do-Nothing) with potential onshore damage	Klassen et al., 1996
			541-5,405/bbl of spilt oil recovered; Onshore oil spillage	Boben, 1996
			7,721 - 772,106/bbl of spilt oil recovered; Spillage in an Environmentally Sensitive Area e.g Exxon Valdez	Boben, 1996
			165-343/bbl of spilt oil recovered; Spill in a rural area that did not impact water.	Winkler et al., 1999
			1,785/bbl of spilt oil recovered; Spill in an Environmentally Sensitive Area on land	Winkler et al., 1999
			9,200/bbl; Spill in an urban area that did not impact water	Winkler et al., 1999
			7,619-12,973/bbl; Spill that impacted a waterway	Winkler et al., 1999
			Bioremediation - no economic data identified	
	Interruption of Operations by Pressure Group	Local	1,700/day; Pressure Group forces delay- facility time for a day	Robin & Pontoriero, 1999
Production				
Controlling emissions to air from power generation	Dry Low Emission Combustion Technology for Gas Fueled Turbines	Local	537,460/turbine (capex); 230-307/Kg of NO_x reduced (opex); Dry Low Emission Combustion Technology for gas fueled turbines. As the primary function of equipment is to provide power, the environmental expenditure to comply with the new regulations will be the marginal cost of upgrading and any modifications to combustion units.	Moltv, 1997
Improving the efficiency of flare stack combustion	Efficient Flare Stack System	Local and Transboundary	Evergreen Burner - 34,320 (Capex); Flame Front Generator (FFG) 7,260; Flare boom: 66,000; HIRE: Evergreen Burners c/w FFG: 792/ day; Flare Booms: 495/ day; Set of 1200 SCFM air compressors: 1,056/ day; Personnel charges: 475/ day / per person	*Personal Communication*, Schlumberger 2000

Development Phase	Environmental Expenditure	Location	Economic Data UK £2000	Source
Controlling the oil in water content in produced water	Hydrocyclones - reduce oil in water content down to 15-35 ppm (throughput: 100-2,500 bwpd)	Local	0.01/bwpd	Orsulik, 1997
	5 Centrifuge System - reduce oil in water content down to 5-20 ppm	Local	Capex 625,000 GBP; Opex 16200/month	Environmental Resources Management, 2000
	Membrane Filtration (Diffusion barrier technology)- reduce oil in water content to <5ppm (throughput 70 bwpd; input oil-in-water >150 ppm)	Local	0.01-0.04/bbl of oil produced	Orsulik, 1997
	Hydrocyclone Downhole Oil/Water Separation Unit (discharge of produced water at surface eliminated); input: 300-800 ppm oil-in-water to formation	Local	61,800 - 171,600/unit; opex: 0.66 bwpd	Rudolph & Rueter, 2000
	Gravity Downhole Oil/Water Separation Unit (discharge of produced water at surface eliminated); input: <500 ppm oil-in-water to formation	Local	10,300 - 17,200/unit; opex: 0.66 bwpd	Rudolph & Rueter, 2000
	Hydrocyclone Downhole Oil/Water Separator (DOWS) Units. Cost excludes workover costs that can often exceed $100,000. DOWS are less energy intensive then surface separation systems and thus do not cause excessive air pollution. They will not work well for wells producing oil with low API gravity	Local	60,000 - 170,000/unit	Veil et al., 1999
	Gravity Separator Downhole Oil/Water Separator Units (DOWS). DOWS are less energy intensive then surface separation systems and thus do not cause excessive air pollution. They will not work well for wells producing oil with low API gravity	Local	10,000 - 17,000/unit	Veil et al., 1999
	API Gravity Separator W/polymer addition	Local	0.1 - 0.175/bbl of oil produced	Orsulik, 1997
	API Gravity Separator WO/polymer addition	Local	0.005 - 0.02/bbl of oil produced	Orsulik, 1997
	Media Filtration	Local	0.01 - 0.04/bbl of oil produced	Orsulik, 1997
	Induced Gas Floatation	Local	0.02 - 0.15/bbl of oil produced	Orsulik, 1997
Controlling fugitive emissions to air	Reducing Methane Emissions from Glycol Dehydrators whilst Drying Natural Gas	Local	*no economic data*	-
	Removal of Hazardous Air Pollutants from Natural Gas using Amine Sweetening Units are widely used by the gas industry (acid gases, VOCs and BTEX)	Local	*no economic data*	-
	Reducing the Volume of Natural Gas bled from Production System	Local	*no economic data*	-

Development Phase	Environmental Expenditure	Location	Economic Data UK £2000	Source
Waste Management	Handling and Disposal of NORM Oil and Gas Field Waste by Licensed Operator	Local, National & Transboundary	212/te	Lyon et al., 1997
	Permanent Low-level Radioactive Waste Facility	Local, National & Transboundary	742/te	Lyon et al., 1997
	Local Re-injection	Local	162.5 - 550/te (capex); 16.35/te (opex)	Environmental Resources Management, 2000
	Re-injection in Remote Facility	Local, National & Transboundary	162.5 - 550/te (capex); 29.4/te (opex)	Environmental Resources Management, 2000
	Ballast Water & Bilge Water Monitoring & Control	National	CAPEX 30,000 per On-line Oil in Water Monitor; OPEX 900 per On-line Oil in Water Monitor (Monitor required for each outfall of water, thus 2 would be required for a shuttle tanker)	Personal Communication Steptech Instrument Services Limited, 27th March 2000
	Non-hazardous Waste Control Systems - incineration	National	150 - 180/te; Incineration of non-hazardous waste	Ness, 1999
	Special Waste Control - plasma incineration	National	240/te; Plasma incineration of hazardous waste	Fosch, 1995
Environmental Monitoring	Produced Oil in Water Monitoring	Local	CAPEX 30,000 per On-line Oil in Water Monitor; OPEX 900 per On-line Oil in Water Monitor (Monitor required for each outfall of water)	Personal Communication Steptech Instrument Services Limited, 27th March 2000
Dealing with accidental and abnormal events	Loss of persistent waste to sea	*See Drilling Section*		
	Clean-up of Contaminated Land			
	Oil Spill Clean-up			
Pipeline Transportation				
Waste Management	Disposal of Waste collected during Pigging	National	*no economic data*	-
Dealing with accidental and abnormal events	Loss of Containment and Oil Spill Clean-up	*See Drilling Section*		
Shuttle-tanker Transportation				
Controlling emissions to air from power generation	Low Emission Diesel Combustion Units	Local	0.22-0.37/kg oxides of Nitrogen & 0.3-0.8/kg Sulphur dioxide emitted (cost data unclear)	The Swedish NGO Secretariat on Acid Rain, European Environmental Bureau (EEB), and European Federation for Transport and Environment (T&E), 2000
Controlling emissions to air from refueling	Emission control systems for refueling operations	Local	33k-660k (capex) - 26k-56k (opex) - he capital cost for emission control systems process vapour from the loading of 10,000 bbl/hour of gasoline. The annual operating costs process vapour from the loading of 10,000 bbl/hour of gasoline	Hill, 1990
Waste Management	On-board vessel waste control systems	Local	no cost data identified	-
Re-design	Upgrading to Double Hulled Tankers	Local	110 million each - *Millennium* ships specifically designed for the weekly run from Valdez, Alaska, to ARCO's refinery at Cherry Point, north of Seattle. The capital cost of a double-hull tanker is estimated to be 9-17% higher than a single tanker, and maintenance and operation costs run 5-13% higher	Martin,1999
Environmental Monitoring	Ballast Water & Bilge Water Monitoring & Control	National	CAPEX 30,000 per On-line Oil in Water Monitor; OPEX 900 per On-line Oil in Water Monitor (Monitor required for each outfall of water, thus 2 would be required for a shuttle tanker)	Personal Communication Steptech Instrument Services Limited, 27th March 2000
Dealing with accidental and abnormal events	Loss of Containment and Oil Spill Clean-up	*See Drilling Section*		

Development Phase	Environmental Expenditure	Location	Economic Data UK £2000	Source
Decommissioning				
Complete removal of facilities	Complete Removal of Steel Platforms (leaving concrete structures, cuttings and pipelines)	Local, National and Transboundary	Case Study: 0.8 bn/15 offshore Ekofisk oil and gas platforms (Removal plan submitted to the Norwegian Oil Ministry. If accepted the Government will pay 72% and the remainder will be split between eight companies).	Phillips Petroleum Company Norway, 1999
			£150-180m/installation (Estimates being quoted at an IBC Conference in London on Decommissioning of Offshore Oil and Gas Installations)	*Personal Communication,* IBC Conference in London on Decommissioning of Offshore Oil and Gas Installations 20-21 January 2000
			Decommissioning cost breakdown: Working of Vessels at Site (4.5%); Pipeline Abandonment & Other Subsea work (12.3%); Topsides Decommissioning and Preparation for Removal (14.1%); Topsides and Jacket Removal (34%) Plugging and Abandonment of Platform Wells (3.2%); Plugging and Abandonment of Subsea Wells (3.2%); Logistical Support (4.3%); Contractor Engineering & Design - decommissioning programme (4%); Administration (7.9%) NOT 100%	Hughes & Fish, 1999 (Estimations based on decommissioning studies undertaken by Foster Wheeler for Southern North Sea Fields)
	Pipeline Removal (Costs compared for pipeline removal, re-installation and preservation in-situ for a 30 km 16" steel pipeline because it is a fairly common size for export or infield transportation)	Regional	S-lay removal for disposal £7.5 m (Offload pipe to pipe carrier vessel)	Damsleth, 2000
			Reeling (removal for disposal) £9m (3 trips required to empty reel - reel has a capacity of 10kms)	
			Trench & Backfill for preservation £3m	
			S-lay for recovery and installation £12.5m (on-boar storage + pipe carrier)	
			Reeling for recovery and installation £12m (3 trips to new site required)	
Disposal and treatment of OBM piles	Leave Undisturbed	Local	0	-
	Re-injection into Remote Reservoir Formation	National, Transboundary	162.5 - 550/te (capex); 29.4/te (opex)	Environmental Resources Management, 2000
	Burial in a Deep Sea Pit	Local, National and Transboundary	No data identified	-
	Spreading	Local	3.5k/pile (Trawling); 692k/pile (Jetting); 583k/pile (Dredging)	Rogaland Research, 1998
	Capping	Local	3 million/pile	Rogaland Research, 1998
	Insitu Bioremediation	Local	No data identified	-
	Large Silos or Concrete Storage Tanks on the Seabed	Local, National and Transboundary	>1 million/pile	Rogaland Research, 1998
	Decommissioning of Drill Cuttings Pile	Local, National and Transboundary	6 million - 10 million (General Estimation Cost)	*Personal Communication,* IBC Conference in London on Decommissioning of Offshore Oil and Gas Installations 20-21 January 2000
	Decommissioning Drill Cuttings Piles	Local, National and Transboundary	£6-10m/cuttings pile	*Personal Communication,* IBC Conference in London on Decommissioning of Offshore Oil and Gas Installations 20-21 January 2000
	Cuttings Disposal	*See Drilling Section*		

Development Phase	Environmental Expenditure	Location	Economic Data UK £2000	Source
Treating the contaminated water from drilled cuttings	Filtration Water Treatment System: Oil content of produced water 5-15 ppm (57 m^3/hour)	Local	3.4/te water (opex); 180,000 - 300,000 (capex)	Environmental Resources Management, 2000
	Supercritical extraction (polishing): Oil content of produced water <5ppm (15 m^3/hour)	Local	2.34/te water (opex); 0.6 million to 1.3 million (capex)	Environmental Resources Management, 2000
Recycling	Recycling Materials (Between 95%-97% of steel can be recycled. 10% of Iron Ore will not be able to be recycled. Estimates being quoted at an IBC Conference in London on Decommissioning of Offshore Oil and Gas Installations)		£50/tonne of Scrap Steel (No details found for recycling Iron Ore ballast)	*Personal Communication,* IBC Conference in London on Decommissioning of Offshore Oil and Gas Installations 20-21 January 2000
Selling second-hand facilities	Top-sides and Jackets Re-sell market	International	*no economic data identified*	-
Dealing with accidental and abnormal events	Loss of persistent waste to sea	*See Drilling Section*		
	Clean-up of Contaminated Land			
	Oil Spill Clean-up			
Others				
Reducing green-house gas emissions using Kyoto Protocol economic instruments	Carbon trading to reduce company global warming gas emissions	Global	20/te (Value of offsetting 1 tonne of CO2 in 1999 by investing in renewable energy and carbon sequestration schemes).	Carbon Storage Trust, 1999
			12/tonne (Average value of 1 tonne of CO2 in 1999 within BP Amoco's internal company carbon trading scheme. The programme of international trading is under development).	Statoil, 1999
Reducing SO_2 emissions using economic instruments	Sulphur dioxide trading to reduce the formation of corrosive acid rain	National	150/te; (Highest recorded value of auctioning of 1 tonne of SO2 in 1998 under US SO2 emission trading scheme for power stations. Alternative is a heavy governmental fine valued at UK £1800 per tonne exceeding thresholds).	Statoil, 1999
Dealing with accidental and abnormal events	Prosecution	National	UK £0.00 (No prosecutions to date).	Department of the Environment, Transport and the Regions. 1998a

6.3. STAGE 2 - TOTAL ENVIRONMENTAL RISK ASSESSMENT

6.3.1 Assessment of the key risks affecting the carrying capacity of the environment

Risks	***Cause***	***Extent of Environmental Change***	***Outlook***
Atmospheric Quality			
• Global Climate Change	*Enhanced global warming due to greenhouse gas emissions*	Climate models currently predict that annual mean air temperatures, above 1990 levels, will increase in global mean temperature of 2°C, within a range of 1.0 –3.5°C, by the year 2100, with higher increases in the north of Europe than in the south. Average sea level is expected to rise by about 50 cm, within a range of 15 - 95 cm by the year 2100. Potential consequences in Europe include increases in sea level; more frequent intense storms, floods and droughts, and changes in biota and food productivity.	Seriousness of impacts depends partly on mitigation and adaptation measures. Ensuring that temperature increase at no more than 0.1°C per decade, at that sea levels rise by no more than 2 cm per decade would require European countries to reduce greenhouse gas emissions by at least 30%-55% by 2010 from 1990 levels. It is uncertain whether the EU will achieve the UNFCCC target set in 1992, of stabilising emissions of carbon dioxide in 2000 at 1990 levels, because emissions are predicted to be to 5% above 1990 levels. Furthermore, the Kyoto target of an 8% reduction in greenhouse gas emissions in 2010, the Commission of the European Communities' latest 'business as usual' (pre-Kyoto) scenario implies an 8% increase in carbon dioxide emissions between 1990 and 2010, with the largest increase (39%) in the transport sector.
• Stratospheric Ozone Depletion	*CFCs, CBCs and HCFCs emissions*	International policy methods taken to protect the ozone layer have reduced annual production of ozone depleting substances by 80%-90% of its maximum value. However time delays in atmospheric processes are such that no effects of the measures can yet be seen in ozone layer concentrations, or in the amount of ultraviolet-B (UV-B) radiation reaching the surface. Total ozone over the North Pole fell to 40% below normal in March 1997. Similar reductions, though less severe, are occurring in Antarctica.	The recovery of the ozone layer will take many decades, and could be accelerated by the phasing out of HCFCs and methyl bromide, by ensuring the safe destruction of CFCs in stores and other reservoirs, and by preventing the smuggling of ozone depleting substances. The ozone depleting potential of all chlorine and bromine species in the stratosphere is expected to reach its maximum between 2000 and 2010.
• Tropospheric Ozone	*NOx emissions*	Ozone concentrations in the troposhere are 3-4 higher than in the pre-industrial era, mainly as the result in very large growth of NOx emissions from internal combustion engines. Emissions of the most important ozone precursors, nitrogen oxides and non-methane volatile organic compounds (NMVOCs), increased in the late 1980s and then fell by 14% between 1990-1994.	Decline in human health and environmental quality from continual exceedances of threshold concentrations. ▪ Threshold concentrations, set for the protection of human health, vegetation and ecosystems, are frequently exceeded in most European countries. About 700 hospital emissions in the EU in the period March-October 1995 may be attributable to ozone concentrations exceeding the health protection threshold. About 330 million people in the EU may be exposed to at least one exceedance of the threshold per year. ▪ The protection threshold for vegetation was exceeded in the entire area of EU forest and arable land in 1995. Exceedances of over 150 days were reported in some sites. Meeting the emission targets for nitrogen oxides set in the Convention on Long Range Transboundary Air Pollution (CLTRAP) and the Fifth Environmental Programme of the European Commission would result in a reduction in peak ozone concentrations of only 5%-10%. Achieving the long-term target of no exceedance of threshold levels will depend critically on reducing overall tropospheric ozone concentrations. This will require measures on emissions of the precursor pollutants covering the whole of the northern hemisphere.
Offshore Marine Environmental Quality			

• Uncertainty over Extent of Degradation	*Chemical discharges*	Data on emissions is scarce, but chemicals are widespread across all environmental media, including animal and human tissues. The European Inventory of Existing Chemical Substances lists over 100,000 chemical compounds.	The threat posed by many of these chemicals remains uncertain because of the lack of knowledge about their concentrations and the ways in which they move through and accumulate in the environment and then impact on humans and other life forms. The difficulty and cost of assessing the toxicity of the large numbers of potentially hazardous chemicals in use, has influenced the development of broad control strategies. The OSPAR Convention on the protection of the North Sea aims to reduce the 'load' of chemicals in the environment through the general elimination or reduction of their use and emissions.
	Heavy metal contamination	Heavy metal emissions to air are decreasing as a result of the removal of lead from petrol. Most European rivers show elevated concentrations of heavy metals. Tributyl tin has been found to cause imposex in shellfish along the British coastline.	Diffuse emissions of cadmium and mercury are difficult to manage and consequently total risk is uncertain. Two new protocols on emissions to air of three heavy metals and sixteen POPs from the UN Economic Commission for Europe have been ratified by 16 signatories under the Convention on Long-Range Transboundary Air Pollution.
	Persistent organic compounds (POPs)	POPs are formed by unwanted by-products and can be difficult to identify and control. High concentrations of organochlorine pesticides and PCBs have been found in the livers of fish from the southern part of the North Sea. The biomagnification of POPs in the food chain to humans (recorded in human milk fat) and other top predators in the region (polar bears) highlights the need for continued attention to this problem.	Although emissions of these substances are falling, concentrations in the environment remain of concern, particularly in some highly contaminated areas and sinks like the Arctic and Baltic Sea. *See above cell.*
	Hydrocarbons	The overall picture of oil is fragmentary, and no reliable assessment of general trends can be made. The main source is from land, reaching the seas through rivers. Although the annual number of oil spills is falling, small and occasional large spills in zones of heavy boat traffic are causing significant local damage, primarily smothering beaches and seabirds, and impairment of harvest of fish and shellfish.	There is no evidence of irrevocable damage to marine ecosystems, either from major spills or from chronic sources of oil. Offshore oil discharges are regulated internationally under Annex I of MARPOL 73/78. The discharge of oil is prohibited from shipping in the North Sea since it was classified as a special area under this convention.
• Low commercial fish stock levels	*Overfishing in the North Sea.*	The total annual catch in the North Sea increased from about 1 million tonnes at the beginning of the century to about 1.8-2.8 million tonnes in the past 15 years. Most of the stocks of commercially exploited stocks are in serious condition. The mackerel stock has collapsed abd shows no sign of recovery. The main exception is the industrial species, which can probably maintain current exploitation levels. Depletion of non-target species is resulting from by-catches in commercial fisheries. By-catch can make up as high as 60% of total catch.	It has been estimated that the North Sea fishing fleet should be reduced by 40% to match available fish resources. Otherwise the over-exploitation will continue to impact on the stability and sustainability of marine life. Impacts may be direct, or indirect through damage to seabed habitats caused by techniques such as beam trawling. There may be indirect, secondary and cumulative effects on other species, including seabirds and marine mammals. Even though the impacts of fishing are difficult to identify there is enough evidence of serious and irreversible damage to require a precautionary principle to be applied to ocean management, as detailed in the Rio Declaration and Agenda 21.
Coastal & Inland Environmental Quality			
• Acidification	*Acid deposition originating from emissions of SO2, NO2 & NH3*	Deposition of acidifying substances has decreased since about 1985. Critical loads are still being exceeded in about 10% of Europe's land area, mainly in northern and central Europe.	The vitality of many forests is still decreasing but, while this damage is not necessarily related to acidification, cumulative impacts of acid deposition on soils may be playing a part. In sensitive areas, acidification leads to greater mobility of aluminium and heavy metals, causing groundwater pollution. Policy measures to combat acidification have been only partly successful: ▪ The target of the protocol of the Convention on Long Range Transboundary Air Pollution (CLTRAP) on nitrogen oxides, to stabilise emissions at the 1987 level by 1994, was achieved by Europe overall, but not by all the 21 parties; and ▪ The Fifth Environmental Action Plan of the European Commission (5EAP) aimed for a 30% reduction in emissions of nitrogen oxides between 1990 and 2000. 1995 achieved an 8% reduction, and it does to appear that the 2000 target will be met.
• Degradation of coastal sights	*Coastal zones are major economic and ecological assets and attract a wide range of human activities*	The population of coastal urban agglomerations is about 120 million in Europe and is continuing to grow. This results in increased competition for limited resources as well as pollution, habitat destruction and coastal erosion. The main sources of litter are probably from shipping.	Continuing pressure to develop coastal areas for housing, industry, tourism, fisheries and other users, coupled with the consequences of climate change, will require rapid implementation of integrated coastal zone initiatives.
• Eutrophication of	*Increasing levels of phosphorous*	Eutrophication, mainly due to the run-off of surplus nutrients from agriculture (60% of	With no general change in nutrient levels entering the North East Atlantic, OSPARCOM & HELCOM aim to reduce the

coastal water	*and nitrate discharges*	anthropogenic nitrogen), is of major concern in the North and other European Seas. Other sources include the cultivation of leguminous crops (25%); fossil fuel burning (12%); biomass burning, draining wetlands and converting woodland to cropland account for the remaining 3%. Nutrient concentrations in many European Seas are generally at the same level as in the beginning of the 1990s. Increases in nitrogen discharges and resulting concentrations in seawater on some of the coats of Europe seem to be correlated with high precipitation and flooding between 1994 and 1996.	discharge of nutrients by 50%, where these nutrients are likely, directly or indirectly, to cause eutrophication. Reform under the EU Common Agricultural Policy (CAP) is being used to integrate measures to reduce nutrient inputs. EU Urban Waste Water Treatment and Nitrate Directive should also deliver improvements.
• Groundwater Degradation	*Increasing levels of nitrate and pesticides*	Groundwater quality is affected by increasing concentrations of nitrate and pesticides from agriculture.	Nitrate concentrations are low in Northern Europe, but high in several Western and Eastern countries, with frequent exceedances of EU maximum admissible concentrations.
Biodiversity			
• Species Loss	*Habitat damage; land use changes; monocultures and the use of exotic species*	The threat to Europe's wild species continues to be severe and the number of species in decline is growing. In many countries half of the known vertebrate species are under threat. More than 1/3 of the bird species are in decline, most severely in north-western and central Europe. Populations of a number of animal species associated with human activities are increasing, and some plant species tolerant to high nutrient levels or acidity are spreading. There has been some recovery in the number of breeding birds in areas where organic farming is practised. The introduction of alien species is causing problems in marine, inland water and terrestrial habitats.	Habitat loss is continuing to occur due to land reclamation, pollution, drainage, recreation and urbanisation. Restoration projects are compensating for these losses though on a small scale. There are a wide range of initiatives and legal instruments that have been introduced to protect species at national and international levels. At an European level the implementation of the NATURA 2000 network of designated sites in the EU and the upcoming EMERALD network under the Bern Convention in the rest of Europe, are currently important international initiatives.
Waste Management			
• Inefficient Resource Usage	*Waste generation rates and quantities*	Reported waste generation in OECD Europe increased by nearly 10% between 1990 and 1995. This increase may be due to improved monitoring and reporting. However there is still a lack of harmonisation and incomplete data collection to make it difficult to identify trends and improve the targeting of waste policy initiatives in Europe. Waste management in most countries is dominated by the cheapest available option: landfill. However, the costs of landfill rarely include full costs (post closure costs), despite the use of waste taxes in some countries (Austria, Denmark and the UK). The is concern over the contamination of soil form land-based disposal methods. Currently, 300,000 potentially contaminated sites have been identified, mainly in western Europe, as requiring remediation.	Waste prevention and minimisation is being increasingly recognised as environmentally more desirable solutions to waste management. All waste streams, particularly hazardous waste, would benefit from further application of cleaner technologies and waste prevention measures. Recycling is increasing in countries with strong waste management infrastructures. A commitment to a sustainable use of resources, minimising environmental damage and following the polluter pays principle and the proximity principle has led the EU to create an extensive range of legislative instruments intended to promote and harmonise national legislation on waste. The UK has a commitment under OSPAR Decision 98/3 to reduce the amount of scrapped platforms associated plant being disposed of offshore.
Central North Sea Industrial Development			
• Oil and Gas Activities	*Substrata oil and gas fields*	The Central North Sea is the most oil productive region on the UKCS. In 1999, there were 72 fields producing in this region; 13 were under development; and, a further 5 had been decommissioned. Exploration has remained at a consistent level between 1996 and 1998, with 12 wells drilled in 1998 of which two were sidetracks. Half of these were obligation wells, primarily on 12th and 16th Round licenses. Appraisal drilling increased from 5 in 1997 to 12 in 1998, although six of these were sidetracks. Two significant discoveries were made in the area, both of which were made on 1st and 2nd Round Licences. One of the discoveries was fast tracked for development.	In 1999, the region has 12 out of 36 UKCS probable developments scheduled, with a total net present value of £570 million. In 1998, in the UK, 23 billion 'barrels of oil equivalent' (boe) have been produced from offshore fields since 1975, with an estimated 20 billion boe remaining. Oil and Gas provide 69% of the UK's energy needs. Generally in western Europe there has been a move from coal and oil to natural gas, nuclear and renewable forms of energy. Natural gas emits less CO_2 per unit energy unit of energy produced than coal or oil, while nuclear and renewable sources emit none, during operation, making switching to other forms of energy, an attractive option to drive down enhanced global warming impacts.

6.3.2 Identification of those environmental aspects generating environmental risks or benefit using environmental impact pathways

6.3.2.1 Solid Materials

1. Presence
2. Discharge of Solid Material
3. Heavy Metals
4. Seabed Disturbance
5. Persistent Waste to Sea or Land
6. Low Specific Activity Scale
7. Injection of Waste into Formation

Presence

IMPACTS

Direct

- Structure 'offers' a substrate for species recruitment and development & roosting site for offshore birds
- Exclusion Zone - Prohibited fishing and/or recreational activity in zone - 500 m for field development
- Visual Offshore 'Eyesore'

Secondary

- Biofouling of facility may increase the levels of organic material in the water column and on the seabed
- There may be socio-economic losses due to the temporary displacement of recreation activities from beach, coastal wetlands, and offshore areas (recreational fishing, shrimping, and crabbing) or a decline in housing purchases or renting, due to construction and operations of fields close to shore, and the construction and transportation noises that are incompatible with beach enjoyment (David et al., 1987; and, Wilman, 1981).

Indirect

- Organic material from the biofouled structure may increase the abundance of bottom dwelling fish. Fallout of organic material will increase productivity in the immediate vicinity of the discharge point, possibly encouraging opportunist species

Cumulative

- *Continuous biofouling and the security offered by the structure subsurface may initiate the* formation of temporary 'haven' for marine fauna and flora by acting as an wildlife aggregating device

Discharge & Disturbance of Sediment into Water Column & onto Seabed

IMPACTS

Direct

- Temporary direct discharge of sediments, including produced sand and drill cuttings, will cause two distinct impacts: the physically smothering of non-motile (sessile) marine organisms; and, an increase the turbidity of surrounding waters. The sensitivity of the environment will influence the significance of the effect. In areas where turbid waters are common place few effects if any will be seen.

Secondary

- Suspension, movement and re-settlement of sediments may destroy suitable habitats for some species and expose infauna to predators and hostile environments.
- Turbidity mitigation measures will significantly cost the water treatment industry if the increased turbidity occurs in waters that are abstracted for drinking water.

Indirect

- If sediments are contaminated the suspension and relocation of sediments would introduce pollutant materials into the water column.

Cumulative

- Increased turbidity and sedimentation may cause an overall change in the ecosystem structure and functioning ability.

Heavy Metals

IMPACTS

Direct

- Heavy metals may be toxic to organisms following ingestion, and begin to bioaccumulate in a food web.
- The formation cuttings themselves may be contributors to the discharge of heavy metals into the environment (Neff & Anderson, 1987).
- Heavy metals may also enter the water column following the dissolution of corrosion protection anodes and antifouling agents.

Secondary

- Exposure risk to fish through bioaccumulation to concentrations of heavy metals from consuming tainted sources. Organ Damage – the liver is often the target of heavy metals as it filters blood before it is pumped through the lungs of terrestrial animals and the gills of aquatic animals. Such toxins directly damage the liver as they are transported in the bloodstream. The liver is susceptible to chemical attack by toxic chemicals as it tries to metabolise substances into forms that may be easily secreted. Such toxins are referred to as hepatotoxins. Similarly the kidneys filter blood are may be damaged by heavy metals referred to as nephrotoxins.
- Socio-economic impact of lost recreation. Anglers are willing to pay for environmental risk information that ensures that whatever they catch, and wherever they catch it, will not expose them to a toxic risk (this includes the testing of sites for chemical contamination of fish and the listing of safe fishing sites) (Krieger, 1994).

Indirect

- *No indirect impacts identified*

Cumulative

- Exposure risk to humans from eating tainted sources that have bioaccumulated concentrations of heavy metals. Heavy metals from drill cutting piles were recorded in a 1988 review by Batelle Ocean Sciences not to bio-acummulate to harmful levels to humans in marine foodwebs (Neff, 1988).

Seabed Disturbance

IMPACTS

Direct

- Physical disturbance of benthic habitats may cause mortality in species populations
- Dredging, scraping, ploughing and trawling the seabed, from chains, ropes, anchors, pipeline and site preparation and clearance operations, damages the seabed. Damage constitutes disturbing sediments, and overturning pebbles and boulders that causes them to abrade against each other.
- Not all benthic communities are equally affected. It is more difficult to detect effects in areas where sediments are highly mobile, while boulder or pebble habitats are more vulnerable.

Secondary

- *Physical disturbance of benthic habitats may cause a displacement of species in the effected zone, but only during and immediately following the disturbance.*
- *There is a generalised model of 'physical disturbance effect'.* Benthic communities respond with losses of erect and sessile epifauna, increased dominance by smaller faster growing species and general reductions in species diversity and evenness (Hall, 1999).

Indirect

- *No indirect impacts identified*

Cumulative

- The settlement of disturbed sediments or rock is likely to occur quickly, but it may take some years for the provision of a new artificial substrate to be colonised by mature communities.

Persistent Waste to Sea or Land

IMPACTS

Direct

- Such materials, which are impervious to rot, are used in the construction of a wide variety of packaging, ropes, seismic and other cables, which, if lost or discarded at sea, can foul propellers of vessels. In particular they present a real hazard to divers and submersibles. They may also become encrusted with algae, barnacles, tunicates and hydroids.
- Materials may be moved considerable distances by water currents and tides, end up on beaches and may eventually arrive on fishing grounds, causing much damage to nets and loss of time to fisherman.
- Plastics may entangle, stress, choke and kill a variety of species marine and coastal turtles, seals

Secondary

- Plastics gradually become weathered fragments and particles that can become ingested by fish, coelenterates and birds, particularly surface feeders. One can only speculate that an accumulation of plastics in the gut be harmful, the only evidence of this is a negative correlation between body fat and the number of particles in the migrating red phalaropes (*Phalaropus faulicarius*) on the Californian coast. If ingested plastic particles are responsible for impairing feeding, this would be detrimental to birds facing long migration (Clark, 1997).

Indirect

- *No indirect impacts identified*

Cumulative

- Local economies will suffer, as fouled beaches are no longer attractive or safe for recreation, or habitation (Wilman, 1981)
- Persistent waste has considerable potential to reduce vertebrate biodiversity. The 'richness' of species or biodiversity is difficult to measure, as most of the estimated 4-40 million species of life are unknown and unmonitored. Vertebrates are highly studied and thus the 50,000 known species provide an indication on the general health of natural communities. It is estimated that 19% of all vertebrates are threatened with extinction and 9% are nearly threatened (Worldwatch Institute, 1998). These numbers suggest that 1 in 4 species of vertebrate are heading for extinction if a *business as usual* strategy is adopted by society. For example, species threatened with extinction include mountain gorilla, beluga whale, peregrine falcon, Siberian crane, Carribean manatee and Asian ('Indian') elephant.

Low Specific Activity scale

IMPACTS

Direct

- Naturally low specific activity scale, or NORM waste, is produced from hydrocarbon reservoirs when injection water and formation water mix together, and a scale precipitated in the reservoir as well as on the inside of the production tubing. The tubing is periodically cleaned and the scale discharged to sea, at <5Gbq/yr with particles <1mm in diameter. The discharge is not considered environmentally harmful in terms of radioactivity.
- NORM refers to any radioactive material that occurs in nature, rather than as a result of human processing or enhancement. The UK Health & Safety Executive's recommended public radiation dose limit is 1 mSv in a year equivalent to a risk of fatal cancer of 1 in 20,000. Studies in the US have calculated that people living close to facilities that treat NORM waste from producing reservoirs, will on average receive an annualised exposure receive 0.02 mSv (Lyon et al., 1997). This is the equivalent to a risk of fatal cancer of 1 in a million. Average annualised worker exposure was calculated to be 0.004 mSv. (Calculating the risk to public has to assume 100% exposure under US law).

Secondary

- Radioactive materials, especially potassium-40, in the sea can bioccumulate in filter feeders such as shellfish. *The contribution of calcium, barium, strontium scales (NORM scales) to radioactive material bioaccumulation in shellfish for consumption was not identified.*

Indirect

- People who eat a lot of shellfish can receive doses well above the average dose received by a person.

Cumulative

- No cumulative impacts identified.
- The worldwide average dose received by a person is 2.7 mSv per year, the corresponding risk of death from cancer is 1 in 7,400. For comparison, the yearly risk of death in Britain from smoking 10 cigarettes per day is 1 in 200, whilst being killed in a road accident is 1 in 17,000, and being murdered is 1 in 100,000 (Gaines, 2000).

Injection of Waste Into Formation

IMPACTS

Direct

- Formation damage may occur. Oil droplets form a thin internal filter cake in the rock that reduces flow, and an external filter cake on the fracture face, that may induce fracturing.
- Other formation damage problems include emulsion and scaling particulate blocking, and a loss of fracture conformance control.

Secondary

- There is a minor risk of fracturing assisting in the vertical migration of oily wastes to the seabed.

Indirect

- *See the effects of hydrocarbons released to the sea.*

Cumulative

- These problems may affect the characteristics of a reservoir and hence of producing wells in the area. However, the overall impact of injecting hot, oily contaminated effluent into the reservoir is little understood and is undergoing study.

6.3.2.2 Energy

1. Disturbance
2. Sound in the Water
3. Sound in the Air

Disturbance

IMPACTS

Direct

- Artificial light sources attract light sensitive species.
- General disturbance to animals and birds by visual startling, e.g. a ship passing close to a seal colony.

Secondary

- The altered behaviour in mobile species e.g. acting as an attraction to migratory birds, plankton or squid species, may interrupt or delay immigration.

Indirect

- Possible startling of certain animal and plant populations may cause them to leave a given site. There is the possibility of return following a cessation of operations.
- Associated developments or activities onshore may be a *nuisance* to local community.

Cumulative

- Regular activity may lead to an acclimatisation and habituation to the source stimulus.

Sound in the Water

IMPACTS

Direct

- Experiments carried out by the Fisheries Research Services in the UK have identified that inshore and reef fish demonstrate a startle reflex to air gun pressure waves. After this reflex, the fish continue on as they were (Wardle, 1998). Investigating the effect of repeated exposure and the effect of sound *on the health of the fish has yet to be undertaken.*
- Serious injuries to fish (eggs to adults) appear to occur at sound levels of 220 dB re 1μPa. This may include internal rupture of tissues leading to bleeding and death.
- It has been identified that fish and other benthic species that do not have a swim bladder are less sensitive to sound (Turnpenny & Nedwell, 1994).
- Offshore fish (pelagics), such as cod, haddock, mackerel and herring, are known to migrate long distances between feeding and breeding grounds. Experiments carried out on these types of commercial fish species has identified large-scale influences to air gun pressure waves, making the fish more or less accessible to fisheries. It is unknown whether seismic surveys can influence large-scale movements of these species (Wardle, 1998).
- The known responses of mammals to seismic surveys include avoidance or approaching; increased or decreased surfacing rates; cessation of feeding, resting or social interaction; changes in vocalisation; decreased heart rates (seals) and decreased vocalisation. Avoidance includes hasty diving or swimming away.
- Studies carried out by Ketten, 1993 and Todd, 1996 identified on post mortem evidence that humpbacks feeding in the vicinity to loud noise suffered ear damage.

Secondary

- Sound levels may disrupt the normal behaviour of species.
- Mammals may experience stress leading to an increased susceptibility to disease.
- *To date there is very little information on the cumulative, indirect and secondary effects upon cetaceans at a species, population, pod or individual level (Evans, 1996).*

Indirect

- Loss of prey may change the population dynamics of a geographical area.
- *To date there is very little information on the cumulative, indirect and secondary effects upon cetaceans at a species, population, pod or individual level (Evans, 1996).*
- Individuals' concerns about whale and dolphin species are characterised the number of subscriptions to conservation and pressure group organisations. The High Court Judgement on the Department of Trade and Industry to minimise impact to populations of whales and dolphins, the result of a challenge by Greenpeace, highlights this further (Lee, 1999). In the past, individuals have been willing to pay to prevent declines in populations of certain sea mammals (Hageman, 1985; and Kahneman and Ritor, 1994).

Cumulative

- Data collated thus far by experts suggest that stationary industrial activity producing continuous noise results in less dramatic reactions by cetaceans than do moving sound sources, particularly ships (Richardson et al., 1995).
- Ambient noise is the result of an accumulation of natural and man-made noise in the oceans. It is considered that as aggregate, ambient noise strongly affects the distance to which marine mammals calls, specific man-made noises and other signals can be detected (Richardson et al, 1995).
- *To date there is very little information on the cumulative, indirect and secondary effects upon cetaceans at a species, population, pod or individual level (Evans, 1996).*
- There is concern over the effects on the distribution of species, their health and related human effects from global environmental change. At the 51st International Whaling Commission meeting, U.S. Commissioner D. James Baker urged the group to better determine how global environmental changes may jeopardise whale stocks throughout the world. "The threats to whales from global environmental change are extremely widespread, and appear to be increasing" (National Oceanic and Atmospherics Administration, 1999).

Sound in the Air

IMPACTS

Direct

- Noise in the air, from the offshore field exploration and production facilities, that is sudden, unusual and above background levels i.e. transient noises, are likely to startle birds causing them to take to flight from their roost or feeding site. Regular or continuous noises are less likely to have an effect.

Secondary

- No secondary effects identified from operations except that individuals may be willing to pay for a reduction in noise if it will better their quality of life (Kriström, 1997).

Indirect

- *No indirect effects identified.*

Cumulative

- Regular activity will lead to acclimatisation and habituation to the source stimulus.

6.3.2.3 Liquid

1. Hydrocarbons released to Sea
2. Oil-based Muds
3. Water-based Muds
4. Synthetic-based Muds
5. Introduction of Foreign Species from Ballasting
6. Chemical Discharges
7. Sewage and other Facility Wastes
8. Brines
9. Injection of Waste into Formation (see 6.3.2.1)
10. Heated Water

Hydrocarbons released to Sea

IMPACTS

Direct

- Toxicity, smothering and clogging may be direct lethal effects from oil spillage.
- Toxicity is largely associated with the aromatic content of crude oil. Heavy oils have seldom caused extensive mortalities of adult fish. Lighter oils have led to extensive mortalities. Planktonic eggs and pelagic fish larvae will be particularly exposed and sensitive to light oil pollution. Some zooplankton species are killed from such exposure.
- There have been few reports of mass mortality of marine mammals from oil pollution.
- The susceptibility of algal species to oils varies enormously. In micro-algae, low concentrations of oil may stimulate primary phytoplankton production whereas high concentrations may lead to a reduction in carbon fixation causing arrest and eventual mortality. Some lower forms of macro-algae are resistant to oil pollution and thrive in polluted environments. Generally if coated in oil, seaweeds will be mechanically stripped from their substrate. High levels of oil inhibit the biosynthesis of nucleic acids and their polymerisation.
- Higher forms of plant life when exposed to oil may tolerate light oilings but heavy fouling leads to mortality. Flowering littoral and saltmarsh plants will suffer from blocked intercellular spaces, increasing respiration and decreasing respiration rates. Flowering and reproduction rates are reduced as a result.

Secondary

- Acute lethal concentrations of oil can alter habitats to the extent that the re-colonisation by plants and animals, as part of an ecological recovery process, may be prolonged. The destruction of marine grazing animals in the intertidal zone upsets the ecological balance. This mortality results in an explosion of green algae which in turn affects other parts of the littoral ecosystem.
- Damage to the littoral fringe and fisheries will result in a loss of earnings for local economies. In the USA "damage coefficients" are reported, which are defined as the lost value per beach day per meter of beach for a beach closed because of an oil or chemical spill; in the case of economic damages to fisheries, calculations are based on allocating the estimated lost stock between commercial and recreational fisheries (Economic Analysis Inc., and Applied Science Associates Inc.,1987; Grigalunas et al., 1988; National Oceanic and Atmospheric Administration, 1983).

Indirect

- Species of marine bacteria utilise oil hydrocarbons as a source of carbon and energy. Over 90 species of such micro-organisms, including fungi and yeasts have been identified being able to degrade petroleum by biological oxidation. Their action does not become important until a week after oil discharge. Molecular configuration of oils influences biodegradability. Alkanes are attacked by more microbial species more rapidly than either aromatic or naphthenic compounds.
- Individuals are willing to pay to avoid oil spill damage to animals, plants and ecosystems. Values have been obtained from WTP contingent valuation studies for these resources (Kahneman, and Ritor, 1994; Rowe et al., 1992; Grigalunas et al., 1988).

Cumulative

- Seabirds and sea otters are the only known groups of marine organisms that have so far been affected by oil pollution to an extent to jeopardise regional populations (Clark, 1997; Kirby, 2000).
- Chronic toxicity may cause interference with feeding and reproduction, abnormal growth and behaviour, susceptibility to predation, and interference with chemical communication. These effects over time can lead to changes in the abundance and distribution of individual species, and shifts in species composition in the oil affected area.
- Biological consequences are more severe if the discharge occurs in the coastal or estuarine environment, particularly in the intertidal zone. Complete recovery of intertidal zones may take over a decade and is dependent on environmental sensitivity and the type of oil contamination.
- Illegal discharges of bilge waters from shipping may contain lubricating oils, which cumulatively can kill marine wildlife and tarnish beaches with tarballs. It has been identified that many of the birds off the east coast of Canada were killed by such cumulating discharges (GESAMP, 1993)

Oil-based Muds

IMPACTS

Direct

- They contain mineral oil, which is of organic origin. This will increase the oil content in the sediment. If it is broken down, it will lead to organic enrichment of the seabed as it increases the natural levels of organic material already present (algae, cellulose and detritus).
- They contain substances that cause irritation upon contact with human skin.
- OBM discharge into the sea decreases benthic biodiversity and abundance of particular organisms. This has been recorded to occur at varying radii from the platform. In 1996 in a comparative study with synthetic based muds, Veil J et al., identified a zone of effect of 500m; Davies J M et al., recorded biological effects up to 3,000 m from the point of discharge; and, other studies have recorded effects following elevated concentrations in sediments up to 6 km from the point of discharge 6 years previous (Olsgard & Gard, 1995).

Secondary

- As biodegradation of any organic material occurs, the enriched area will develop anoxic and hypoxic conditions. If prolonged this will enable sulphate-reducing bacteria, typically found in deep sediments, to survive in surface sediments where they can produce potentially lethal concentrations of H_2S (Pearson and Rosenberg 1978). There will be a modification of benthic fauna at all levels, by the loss of marine life as dissolved oxygen levels in sediments and the water column lower. As intolerant species are lost and opportunist species in the ecosystem increase in numbers, species diversity will be reduced in the wider area.

Indirect

- There are species resistant to severe and moderate hypoxia, but also those that are sensitive. Hypoxia in benthic species effect on: community structure and function, the mass elimination of macrofaunal species shifts populations toward smaller and short-lived species that possess opportunistic life histories. These new communities are highly stable of high abundance and biomass, and low diversity (Diaz & Rosenberg, 1994).
- OBM cuttings are no longer discharged offshore but are either brought a shore or injected into a well. Onshore they are either recycled or reused, or disposed of on land. Cuttings are treated for safe landfill disposal but increasingly there are a diminishing number of landfill sites and regulations are changing that this may no longer be a disposal option. There may be a risk toxic hydrocarbons and priority pollutants leaching and contaminating groundwater supply. Energy is used in transporting and injecting spent drilling fluid and cuttings. This is in the form of diesel fuel, which on combustion produces various air pollutants. The US Environmental Protection Agency (EPA) estimated that the US receives an additional 298 tons/year of additional air pollutants from the supply boats that transport mud and cuttings.

Cumulative

- Fish exposed to OBM cuttings for 30 days showed an accumulation of mineral oil in the guts, and about half of the tested fish showed accumulation in the tissues (Friedham & Pantermuehl, 1993).
- The amount of atmospheric pollutants emitted is less with OBMs. This is because OBMs reduce drilling times and the amount of energy required to drive the rotary table.

Water-based Muds

IMPACTS

Direct

- WBM's minor constituents include inorganic salts, surfactants, detergents, corrosion inhibitors and lubricants Generally considered being low toxicity mud. Any toxic components in the mud will kill sessile species and may cause mobile species to migrate from the site.
- WBMs do not agglomerate like OBMs and so spreads to form a thin and extensive covering on the seabed, which may smother sessile benthic organisms.
- If they contain a high level of organic components, organic enrichment of the seabed may occur if the organic carbon is taken up by the benthos.

Secondary

- WBMs contain organic compounds. This is further enhanced if they have been contaminated with diesel or mineral based oil. As biodegradation of any organic material occurs, the enriched area will develop anoxic and hypoxic conditions. If prolonged this will enable sulphate-reducing bacteria, typically found in deep sediments, to survive in surface sediments where they can produce potentially lethal concentrations of H_2S (Pearson and Rosenberg 1978). There will be a modification of benthic fauna at all levels, by the loss of marine life as dissolved oxygen levels in sediments and the water column lower. As intolerant species are lost and opportunist species in the ecosystem increase in numbers, species diversity will be reduced in the wider area.

Indirect

- WBMs are discharged into the sea onsite and therefore no atmospheric pollution is incurred with transporting or re-injecting cuttings.

Cumulative

- The US Environmental Protection Agency identified no regional scale effects from the use of WBMs (EPA, 1993).
- One year after terminating drilling, no adverse effects, including chronic, were recorded from a study on WBM cutting discharge on the benthic community in the Dutch Sector of the North Sea. After 2 months no significant effect was detected 25 metres from the former point of discharge (Daan & Mulder, 1993).
- In 1984 a benthic evaluation of a deep, 390 ft, low energy site off the coast of New Jersey, USA identified that WBM cutting discharge caused local a local decrease in the abundance of immobile, bottom dwelling organisms. The discharges had a minor effect on biodiversity. The abundance level of bottom dwelling fish increased due to the additional bottom micro-relief provided by the cuttings and the fall out of organic material form organisms attached to the submerged portions of the platform (Neff, 1988).
- WBMs discharged to high-energy environments produce minor changes to the benthic community during and immediately after drilling. In a study at the Georges Bank, USA these changes were identified to be within the range of natural variation and appeared to have no effect on the benthic invertebrate and fish populations that support a rich commercial fishery (Neff et al., 1989).

Synthetic-based Muds

IMPACTS

Direct

- SBMs are a diverse group of substances with widely different base fluids and thus, they present varying levels of toxicity to marine organisms.
- Polyalphaole-fin (PAO) based SBMs have a higher a higher flash point than flash point than mineral or diesel based oils resulting in less fumes being released during drilling.
- SBMs become contaminated with oil from :

1. crude oil while drilling (influx of formation fluid/kick),
2. diesel oil from contact with OBM during shipping to and from the well, at the mixing plant or during storage between jobs,
3. mineral oil from contact with mineral oil OBMs (oil pills),
4. other contaminants such as surfactants, detergents, lubricating oils, hydraulic oils, that are found on the well site, in the mixing plants or in the boats that transport the muds (Churan et al., 1997)

Secondary

- SBMs contain organic compounds. This is further enhanced if they have been contaminated with diesel or mineral based oil. As biodegradation of any organic material occurs, the enriched area will develop anoxic and hypoxic conditions. If prolonged this will enable sulphate-reducing bacteria, typically found in deep sediments, to survive in surface sediments where they can produce potentially lethal concentrations of H_2S (Pearson and Rosenberg 1978). There will be a modification of benthic fauna at all levels, by the loss of marine life as dissolved oxygen levels in sediments and the water column lower. As intolerant species are lost and opportunist species in the ecosystem increase in numbers, species diversity will be reduced in the wider area.

Indirect

- SBMs may be discharged on site or transported back to shore to be recycled (reconditioned) for re-use. Direct discharge reduces any air pollutants emitted during transportation, however that depends on whether a 'specific disposal trip' is made or whether the mud is transported on a normally scheduled supply vessel trip.

Cumulative

- SBMs have shorter drilling times comparative to WBMs and therefore the level of air pollutants, per metre drilled for the same rock type and bit, would be lower.
- A Norwegian field study recorded a 100 m zone of effect from SBM cuttings discharge and within 1 year populations were classified as 'back to normal' (Gjos, 1991).
- In a study by Chandler et al., in 1995, PAO type SBM cuttings discharged 2 years previously into 128 ft of seawater adversely affected a 50 m zone (Candler et al., 1995). The elevated levels of 'total petroleum hydrocarbons' (TPH) acted as an indicator of PAOs.
- An Australian field study in the Bass Strait identified minor long-term environmental risks to benthic fauna from the discharge of Ester SBMs. It further recorded: negligible measurable effect from elevated barium concentrations on the biota; localised biological effect (within 100 m from point of discharge); and a 4 month ecosystem recovery, attributable to biodegradation and hydrodynamic dispersion processes. Biological effects were primarily recorded as reductions in the number of taxa at Class level. Variations at family and genus level appeared variable (Terrens et al., 1998).
- The use of ester SBMs in the North Sea has reduced the abundance and species richness up to 3000 m from the well. These effects disappeared after one year (Dan et al., 1996).
- A study by Hanni et al., in 1998, identified that, assuming less than 5 g of synthetic material per 100 g dry weight cuttings, invert drilling fluids utilizing synthetic base fluids do not produce a cutting pile, are low toxic, do not bio-accumulate and are biodegradable (Hanni et al., 1998).
- The majority of the synthetic mud based systems discharged into the UKCS waters are 'Category E' ranking in the Offshore Chemical Notification Scheme (OCNS) and are therefore, relatively non-toxic, unbio-accumulating and biodegradable (Munro et al., 1997).

Introduction of Foreign Species from Ballasting

IMPACTS

Direct

- There is the potential for the introduction of alien species as the estimated number of species in motion at any one time in ballast water of ships in oceans > 3000 (Independent World Commission on the Ocean, 1998).
- Contaminated ballast water discharged to sea may cause subtle metabolic changes in species, accumulation in biological tissues, and chronic and/or acute toxicity, which could in extreme circumstances lead to mortality. The extent of effect is highly variable. The significance of the effect is dependent upon the sensitivity of the ecosystem to the alien species, and the ability of the alien species to survive in its 'new' environment
- Significant effects are unlikely for vessels that travel short distances thereby reducing the possibility of introducing foreign species. Potential environmental risk increases with distance particularly for vessels motoring along international shipping routes

Secondary

- The introduction of new species can be a nuisance and may lead to a decline in the number of a indigenous species in an affected ecosystem. The number of non-indigenous species in the Central and Northern Baltic Sea is 35; and in San Francisco Bay it's >150 where densities of the introduced Chinese clam in parts of the bay are 10,000 per m^2 3000 (Independent World Commission on the Ocean, 1998).

Indirect

- The UK public is seriously concerned about the health of the marine environment. This is highlighted not only in surveys but also in demonstrations against adverse degradation (DETR, 1998a; Scottish Office, 1991; FOE, 1999; Shell UK Ltd, 1998a).

Cumulative

- Fisheries may be damaged from the introduction of foreign species. Estimated losses to fisheries in the Black Sea as a result of the introduced comb jelly fish *Mnemiopsis leidyi* were US $ 300 million.

Chemical Discharges

IMPACTS

Direct

- Due to the highly varied discharge, the potential effects to the environment are unclear: they may include subtle metabolic changes, accumulation in biological tissues, and chronic and/or acute toxicity, which could in extreme circumstances lead to mortality.
- Dilution to non-acutely harmful levels should occur within 20-50 metres of the discharge point. However, there is evidence that some chemicals may have an effect up to 500 metres in deep water. The zone of potential effect could be larger in shallower waters e.g. 1,000 metres. In areas of good mixing offshore near installations there have been no recorded effects on seabed or water column communities from bilge water discharges.

Secondary

- The bio-accumulation of contaminants in the tissues of organisms is complicated by the varying effects that may arise from similar contaminants being present in different forms with different availabilities for uptake.
- Individuals are willing to pay for improvements in areas where coastal and inland water quality is being declined and consequently needs improving (Kawabe and Oka, 1996).

Indirect

- The bio-accumulation of contaminants in food chains presents a risk to individuals that ingest tainted fish or shellfish.

Cumulative

- The complexity of the ecosystem and, the occurrence of a multitude of contaminants make it difficult to identify effects. Most contaminants enter the UK seas by outflows and runoff from the land. The highest concentrations are often found in coastal and estuarine areas and thus effects of the ecosystem can be expected to be the strongest here. On entering the sea contaminants are widely dispersed and diluted. Additional sources include shipping, offshore platforms and inputs from the atmosphere. They are also adsorbed onto suspended particulate matter, which where settled, will elevate contaminant concentrations. This has been identified to occur at the Dogger Bank, the Oyster Ground, the Wadden Sea, the German Bight, the Skagerrak, and the Norwegian Trench (North Sea Task Force 1993).
- Alkyl-phenol ethoxylates used for detergents, emulsifiers, lubricants and stuck-pipe release agents are partially biodegradable under aerobic and anaerobic conditions, producing products, which are more toxic than the parent product. They act as an oestrogen mimic and may bioaccumulates in fish causing sterility in males, causing concern over effects further up the food chain to humans (MRC Institute for Environmental Health, 1995).

Sewage and other Facility Wastes

IMPACTS

Direct

- Organic material discharge causes localised smothering of species and can organically enrich local sediments if carbon is taken up, as it increases the natural levels of organic material already present (algae, cellulose and detritus). In the worst cases, oxygen is depleted resulting in mass mortality of species.
- Sewage may be treated with chlorine. Where it is, any free chlorine may interact with hydrocarbons and other organic components potentially forming organochlorine compounds. The fate and significance of these in marine ecosystems has yet to be determined. Tainting may occur to sessile or resident organisms in the water column upon exposure. Under usual discharge conditions, even in the photic zone and at the sea surface, such interactions are unlikely to produce high concentrations of compounds more complex than mono- and di-substituted aromatics such as the chlorophenols. Chlorination is best avoided at installations close to shallow beds of commercially harvested invertebrates or ground fisheries.
- Faecal coliforms (large group of bacteria which inhabit the intestinal tract of man and are past out in faeces) are representative indicators of sewage contamination and their presence in a sample is used to indicate the presence of other pathogens, which could be harmful to human health. Survival of viral pathogens have been shown to be considerably greater (several months) than faecal coliforms (about 24 hours) the latter being destroyed by sunlight and seawater.

Secondary

- Offshore enrichment of natural waters with inorganic nutrients promotes phytoplanktonic growth, which increases biomass and decomposition.
- As biodegradation of any organic material occurs, the enriched area will develop anoxic and hypoxic conditions. If prolonged this will enable sulphate-reducing bacteria, typically found in deep sediments, to survive in surface sediments where they can produce potentially lethal concentrations of H_2S (Pearson and Rosenberg 1978). There will be a modification of benthic fauna at all levels, by the loss of marine life as dissolved oxygen levels in sediments and the water column lower.

Indirect

- There are species resistant to severe and moderate hypoxia, but also those that are sensitive. Hypoxia in benthic species effect on: community structure and function, the mass elimination of macrofaunal species shifts populations toward smaller and short-lived species that possess opportunistic life histories. These new communities are highly stable of high abundance and biomass, and low diversity (Diaz & Rosenberg, 1995)
- This presents risks of reduced species diversity and complete ecosystem deterioration. In most cases the enhanced possibility for phytoplankton growth lead to shifts in the species composition of the algae, which becomes dominated by types that can absorb the supplied nutrients most quickly. Phosphate and nitrogen eutrophication leads to a shift of the system from diatoms (which need also silica) to phytoflagellates. Food chains change accordingly, and the eutrophicated area becomes unsuitable for many species that lived there before (Hanneka et al., 1998).

Cumulative

- Hypoxic and anoxic ecosystems have existed through geological time, with certain species evolving to exploit them. It has been recorded that globally, most estuarine and coastal waters are affected by, through the process of eutrophication, hypoxia and anoxia. There are a large number of studies on the degradation of coastal, fjordic and offshore ecosystems due to hypoxia across the world. As early as 1983, the North Sea, west of Denmark was classified as severely hypoxic (Dyer et al., 1983).
- Some phytoflagellates produce toxins, which bioaccumulate in food chains. These are harmful and sometimes fatal to humans when digested in predatory fish. Blooms of such organisms tend not to be related to pollution however their increase in recent years, with serious public health consequences, has lead to concern that nutrient enrichment of water may be a contributory factor (Clark 1997). Biotoxins include Ciguatera (South East Asia), Paralytic Shellfish Poisoning (UK, Philippines and USA), and Neurotoxic Shellfish Poisoning (USA).

Brines

IMPACTS

Direct

- The high salt content of brines makes discharges dense causing plumes to travel down toward the seabed. There may a possibility of the plume striking the seabed. Elevated saline conditions may provide unsuitable conditions for plankton. Most benthic and pelagic species are unaffected.
- Ambient crossflow may be strong enough to disperse and dilute any discharge. Similarly dilution increases with depth.
- Any effects will be short lived as brines are discharged as a well completion fluid.

Secondary

- No secondary impacts identified

Indirect

- No indirect impacts identified

Cumulative

- No cumulative impacts identified.

Heated Water

IMPACTS

Direct

- Thermal pollution will stimulate planktonic growth and marine fouling of structure. For certain species, eg sea trout, an increase in temperature is life threatening. For other species warmed water may be considered beneficial.
- Most plumes are buoyant due to the increased water temperature. Thus a near seabed release depth is preferred to achieve maximum and cooling.

- Thermal additions and their immediate benefits to producers can promote fish growth and improve fishing activity in the area
- If an increase in temperature has an adverse impact on a species that supports an ecosystem or another population of species then a knock-on effect can be predicted. It has been generally found that tropical marine animals are less able to withstand temperature fluctuations when compared to those in temperate regions (Clark, 1997).

- No indirect impacts identified.

- As water temperature increases two factors combine to make it difficult for marine life to get sufficient O_2 from water. Metabollic rates increase, generally by a factor of 2 with each 10°C rise in temperature. This causes an increase in the amount of O_2 required by organisms. Also, the available supplies of dissolved O_2 (DO) are reduced by a faster assimilation of waste that reduces DO at a faster rate, and temperature. As temperature increases, the amount of DO that the water can hold decreases. Thus as temperature increases, O_2 demand increases and while the actual dissolved amount goes down.

6.3.2.4 Atmospheric Emissions

1. CO_2
2. CO
3. Oxides of nitrogen
4. SO_2
5. CH_4
6. CFCs/HCFCs/CBCs
7. VOCs
8. H_2S
9. Particulates (PM_{10})
10. Odour

Carbon dioxide

IMPACTS

Direct

- Non hazardous, natural gas produced by animals in respiration and required by plants for photosynthesis.
- World carbon emissions* have increased nearly four-fold since 1950. The annual emission of carbon from the burning of fossil fuels rose 107 million tonnes in 1997 to a new high of 6.3 billion tonnes. The 1.5-% increase on 1996 was due to continued emissions growth in the industrial and developing worlds. This increase in carbon emission coupled with a 1997 record high for global temperature is focusing attention on global warming. The air temperature on the earth's surface in 1997 averaged 14.4 degrees Celsius according to the Goddard Institute of Space Studies in New York (Worldwatch Institute, 1998).

Secondary

- Enhances photosynthesis of plants. The effects do not discriminate between species particularly those regarded as pests.
- An increasing global temperature thermally expands water and melts land and floating ice. Global sea level has risen by between 10 and 25 cm over the last 100 years and projections of future changes estimate that sea level will be approximately 50 cm higher than it is today by the year 2100 (Department of the Environment, Transport and the Regions, 1998a).
- Temperatures exceeding comfortable limits will cause thermal stress, both in the cold and warm range, and will substantially increase the risk cardiopulmonary illness and death.
- There are studies that have examined and identified a range of socio-economic benefits from greenhouse gas emission reductions in the United States & Europe (Externe Programme 1998; IPCC, 1995).

Indirect

- As well as potential increases in agricultural productivity in temperate regions, those characterised by semi-arid, arid and tropical conditions will experience a decline in agricultural productivity.
- On low-lying atolls in the Pacific, people are radically change the way they grow crops, because rising sea levels are seeping into the soil, making it too salty to grow staple crops such as taro, pulaka and yams. Tebua Tarawa and Abanuea, two uninhabited islands of the Pacific nation of Kiribati have disappeared under water. (The South Pacific Regional Environment Programme, 1999).
- The UK and US public have been identified as being willing to pay (WTP) compensation to future generations particularly those in the worst affected areas for the greenhouse effect (Spash, 1993). Studies have verified this concern (DETR, 1998a; Dunlap & Mertig, 1992; Scottish Office 1991).

Cumulative

- By the middle of the next century tropical grasslands and forests will be at risk of decline whilst temperate and boreal forests may continue to expand. In the second half of the century the ability of vegetation to absorb man-made CO_2 would decline, accelerating the increase in atmospheric CO_2 concentrations. Climate change would also put pressure on water resources, particularly in Africa, Central America, the Indian subcontinent and Southern Europe. By the middle of the century it is estimated that a further 100 million people would be suffering extreme water stress and by the second half of the century, regional reductions in crop yields could lead to increased hunger for some 50 million people in the tropics, particularly in Africa. At the same time about 200 million people could be affected by sea level rise world-wide, particularly in the heavily populated areas in the Southern Mediterranean, Africa and Southern and South-east Asia. 25 per cent of the World's coastal wetlands could be lost by the end of the century as a result of sea level rise alone (Department of the Environment, Transport and the Regions, 1998a).
- A decline in agricultural productivity will have significant public health consequences; changes in the behaviour and geographical distribution of vector-borne diseases; increases in non-vector-borne infectious diseases; reduced environmental resources will stimulate conflicts; increased production of secondary air pollutants will irritate allergic disorders and increase the number of cardiorespiratory deaths (Martens, 1998).

Carbon monoxide

IMPACTS

Direct

- It is a poison that reduces the ability of the body to absorb oxygen. It is particularly dangerous to foetuses.
- Low concentrations can decrease cognitive and motor functions producing headaches and drowsiness.

Secondary

- Impairment of O_2 supply to the brain can result in irreparable damage.

Indirect

- *No indirect effects identified*

Cumulative

- *No cumulative effects identified.*
- *To ensure the greatest benefits to the population as a whole the UK Expert Panel on Air Quality Standards (EPAQS) has recommended CO level of 104.6ppb as a one-hour mean, with 20ppb as an annual mean (EPAQS, 1994).*

Oxides of Nitrogen

IMPACTS

Direct

- Low levels of NO_2 may stimulate growth by increasing soil nitrogen levels through dry deposition. Whilst this is beneficial for crops, it is considered unacceptable for native species (Farmer, 1997). This is because many habitats and their species are nitrogen limited.
- NO_x reacts with water to form nitric acid forming acidic precipitation and acidifying of receiving Water/Soil/Vegetation
- Exposure of plants to 380 ppb NO_2 inhibits photosynthesis (Bennet et al., 1990). This effect is enhanced in the presence of SO_2 to 80 ppb NO_2.
- Depletion of the Ozone layer (N_2O) (Wolhius et al., 1991).

Secondary

- Leaching of the soil of valuable nutrients and mobilisation of heavy metals
- Loss of aquatic life
- Formation of a secondary pollutant – ground level ozone. HCs are degraded in the atmosphere by the presence of hydroxl free radicals (OH). This produces a peroxy radical which oxides NO to NO_2. This dissociates to NO, producing an O_2 free radical (O). This reacts, in the presence of sunlight, with O_2 to produce ozone (O_3). These reactions take days to complete and thus may not occur near the source of the primary pollutant.

Indirect

- Plants are Susceptible to Drought and Pathogens (Growth Rates of Aphids are Higher on Plants Exposed to Ozone)
- Visibility Reduced by Light Scattering Through Ozone
- O_3 can Increased Severity of Asthma (at 100ppb) or breathing difficulty in elderly and Cardiorespiratory Disorders
- Individuals are concerned about and are willing to pay for improvements in air quality, particularly those with an interest in outdoor activities (Department of the Environment, Transport and the Regions, 1998a; Farber and Rambaldi, 1993; Scottish Office, 1991; Brucato et al., 1990). See CO_2 for public opinion on global warming impacts.

Cumulative

- Causes longer-term damage to plants functioning within ecosystems if critical levels are above 30μg/m^3 (annual mean) or 95μg/m^3 (4-hour mean) (Ashmore & Wilson, 1994).
- Global Warming: Sea Level Rise; Air Pollution; Weather Disasters; Vector-borne Diseases; Marine-borne Diseases; Food Productivity (see Carbon dioxide).
- There are studies that have examined and identified a range of socio-economic benefits from greenhouse gas emission reductions in the United States & Europe (Externe Programme 1998; Burtraw and Toman, 1997; IPCC, 1995).

Sulphur Dioxide

IMPACTS

Direct

- Acid precipitation – SO_2 reacts with O_2 to give SO_3, which reacts with rainwater to give acid rain (dilute H_2SO_4) and sulphate particulate matter. Acid mists may damage leaves of plantation forest *trees.*
- Most lichens are sensitive to SO_2 which readily absorb the pollutant and it is highly toxic to their metabolic function.
- Sulphur dioxide causes an irritant effect in the respiratory tract affecting individuals with asthma and those with lung diseases.
- Structural damage to buildings

Secondary

- Leaching of the soil of valuable nutrients.
- Loss of aquatic life onshore as pH or receiving waters decreases.
- At 4000ppb SO_2 causes narrowing of airways for 5 minutes for healthy individuals. This effect occurs at 200ppb for asthma sufferers. There is concern that sulphate particulate matter may be carcinogenic (Hatamian, 1997).
- Acidification of forestry and inland waters will result in socio-economic losses (Burtraw et al., 1997).

Indirect

- Plants may become more susceptible to drought or pathogens.
- Individuals in the US are willing to pay for reductions in SO2 emissions so that there will be a reduction in impacts on population health (Burtraw et al., 1997; Joyce et al., 1989).
- Atmospheric pollution and acid rain are public concerns. Studies in England & Wales have identified that localised atmospheric pollution is a major future concern for the public (DETR, 1998a). The US public have been willing to pay to protect lakes from the progressively severe effects of acid rain, such as the loss of fish, water birds and the thinning of forests (Welle, 1986).

Cumulative

- Ecosystem, forestry, agriculture production and freshwater fishery decline.
- Decline on tourist visits to parks.
- Aesthetic deterioration to residential areas.
- To ensure the greatest benefits to the population as a whole the UK Expert Panel on Air Quality Standards (EPAQS) has recommended a SO_2 standards of 100ppb over a 15 minute averaging period (EPAQS, 1995a). In Britain, it is rare to find winter mean concentrations of SO_2 over 10 $\mu g/m^3$.

Methane

IMPACTS

Direct

- Also known as marsh gas, it is produced naturally in the ecosystem either during the decomposition of organic material or by natural seepage. Decomposition may be aerobic by ruminants, particularly stall-fed cattle, and *anaerobic* by methanogenic bacteria.
- Enhanced global warming – increase in average global temperature leading to sea level rise, increased rainfall in wet areas, increased frequency of severe droughts in dry areas and shifting species ranges. It has a global warming potential 21 times that of carbon dioxide. Methane has an atmospheric lifetime of ~10 years (Hatamian, 1997). *For enhanced global warming impacts see carbon dioxide.*

Secondary

- *For enhanced global warming impacts see carbon dioxide.*

Indirect

- *For enhanced global warming impacts see carbon dioxide.*

Cumulative

- *For enhanced global warming impacts see carbon dioxide.*

CFCs /HCFCs/CBCs and other Halons

IMPACTS

Direct

- The non-toxic and stable nature of these compounds have made them ideal for refridgeration, foaming agents, solvents and aerosol can sprays
- Enhanced global warming – increase in average global temperature leading to sea level rise, increased rainfall in wet areas, increased frequency of severe droughts in dry areas and shifting species ranges. 1 kg of CFCs or CBCs has a global warming potential equivalent to between 5,000 – 6,500 kg of CO2 over a twenty year period (Albritton et al., 1995). *For enhanced global warming impacts see carbon dioxide.*
- Depletion of the Ozone layer – gases enter the stratosphere as chlorine components which are dissociated by solar UV and resulting chlorine radicals destroy the ozone layer
- Increased levels of ultraviolet radiation (UV) may have serious consequences for living organisms. Adverse effects of UV-B have been reported on terrestrial plant growth and photosynthesis. Increased levels have also been shown to have a negative effect on aquatic organisms, especially those at the base of any food web or chain e.g. phytoplankton, zooplankton, larval crabs and shrimps, and juvenile fish.
- UV-B affects tropospheric air quality and may cause damage to materials such as wood, rubber and plastics.

Secondary

- Agricultural production decline. A reduction of the world's food production is a pressing significant risk when coupled with rapid population growth.
- The cost of treating skin cancer has been identified as exceeding defensive expenditures as part of a study designed to identify the benefits of ozone preservation (Murdoch & Thayer, 1990).
- *For enhanced global warming impacts see carbon dioxide.*

Indirect

- Despite the very low concentrations of halon-1211, the researchers have determined that continued increases of this gas are slowing the collective decline of ozone- depleting chemicals in the atmosphere more than any other persistent man-made gas. CBCs have a significant influence on stratospheric ozone because they contain bromine, which is about 50 times more efficient at destroying ozone than the chlorine released by CFCs. Considering this enhanced efficiency, all halons account for about 10-15% of the ozone-depleting potential of today's atmosphere.
- *For enhanced global warming impacts and public opinion see carbon dioxide.*
- The US public are willing to pay to reduce and prevent the risk of skin cancer from ozone depletion (Dickie and Gerking, 1996)

Cumulative

- A long-term increase in UV-B radiation due to stratospheric ozone depletion will cause an increase in melanoma skin cancer and non- melanoma skin cancer. Sensitivity to such cancers will depend upon an individual's level of pigmentation. The incidence of various diseases to the eye, particularly pterygium and cataracts, is also likely to increase. There is less certainty about whether damage to the human immune system (both local and systemic) could occur. Scientists from government and academia have confirmed that most of the gases responsible for stratospheric ozone depletion are produced by human activities and are not naturally occurring in the atmosphere. Measurements of air trapped in polar snowpack (called firn) in Antarctica and Greenland reveal for the first time that the major ozone-depleting gases were not present in detectable amounts in the atmosphere in the late 19th and early 20th centuries. Ice cores have been analysed previously for more abundant atmospheric gases such as carbon dioxide, but there is not enough air trapped in ice core samples to enable researchers to detect the part per trillion levels of the ozone-depleting halogen-gases. The data, which were obtained at two sites in Antarctica and one site in Greenland from depths of up to 120 meters, are consistent with suggested anthropogenic (human-caused) emission histories (NOAA, 1999).
- *For enhanced global warming impacts see carbon dioxide.*
- There is no record of the overall contribution of the upstream sector to Halons consumption. In the early 1990s the overall petroleum industry is estimated to contribute to some 10% of the global contribution (Parums 1993). Since this time operators are significantly reducing their usage.

Volatile Organic Compounds (VOCs)

IMPACTS

Direct

- Irritant and direct toxic effects
- Enhanced global warming – increase in average global temperature leading to sea level rise, increased rainfall in wet areas, increased frequency of severe droughts in dry areas and shifting species ranges. *For enhanced global warming impacts see carbon dioxide.*

Secondary

- Formation of a secondary pollutant – ground level ozone (O_3). Serious health hazard photochemic smog. Human health effects include increased severity of asthma (at 100ppb) or breathing difficulty elderly.
- The degree to which VOCs contribute to ozone formation depends on ozone the quantity emitted. Each VOC is ascribed a photochemical a 'photochemical ozone creation potential' (POCP).
- Decreased native plant and crop productivity.
- *For enhanced global warming impacts see carbon dioxide.*

Indirect

- Growth rates of aphids are higher on plants exposed to ozone and this may affect crop yield (Brown et al., 1992)
- *For enhanced global warming impacts see carbon dioxide.*

Cumulative

- Ozone Layer Depletion
- *For enhanced global warming impacts see carbon dioxide.*

Dihydrogen sulphide

IMPACTS

Direct

- When bacteria decompose organic sulphur compounds, particularly in swamp and seafloor anaerobic sediments, the initial excreted sulphur product is generally dihydrogen sulphide (H_2S). Dihydrogen sulphide is rapidly oxidised to from sulphur dioxide in air. Acid precipitation – SO_2 reacts with O_2 to give SO_3, which reacts with rainwater to give acid rain (dilute H_2SO_4) and sulphate particulate matter. Acid mists may damage leaves of plantation forest trees. In water it will react with metal ions in the sediment or water column to form insoluble sulphides. The black colour of sediments is partially due to the presence of iron sulphides as well as organic matter.
- H_2S is a colourless poisonous gas with a smell of bad eggs, thus in poorly ventilated areas and sufficient concentrations it will kill. Recent research has identified that minor exposures can reduce lung residual volume. It is suggested that the decrement in residual volume, in the presence of other normal indices of lung function, could represent a sub-acute manifestation of dihydrogen sulphide intoxication (Buick et al., 2000).
- *See Sulphur Dioxide for related impacts.*

Secondary

- The association of sulphide minerals, particularly iron pyrites, with rich organic matter can lead to acidity when exposed to the atmosphere. This is due to a redox reaction that can occur in the presence of water, oxygen and micro-organisms, that leads to the formation of sulphuric acid. The acid produced will be neutralised as it passes through rocks and soil, however in the process, extensive leaching will occur. Cuttings piles brought ashore therefore require treatment to ensure that concentrations of potentially toxic elements, and the increased mobility of these elements in acid waters, do not bioaccumulate in plants and aquatic biota. Poor treatment of former oil-based mud drill cuttings material could lead to major pollution problems, similarly to those of metalliferous mine-waste dumps.
- *See Sulphur Dioxide for related impacts.*

Indirect

- Bioaccumulation and biomagnification of toxic elements in organisms in food chains.
- *See Sulphur Dioxide for related impacts.*

Cumulative

- Ecosystem, forestry, agriculture production and freshwater fishery decline. Mollusca and crustacea are more sensitive to acidity than fish and rarely survive below pH 6.
- Decline on tourist visits to parks.
- *See Sulphur Dioxide for related impacts.*

Particulates

IMPACTS

Direct

- Not all particulates have an equal effect on human health. Particles less than 10μm diameter (PM_{10}) will penetrate into the deeper parts of the lung causing irritation. Mucus secretions remove larger particles (Farmer, 1997).
- Particulates may block leaf stomata (8-12 μm diameter): the pores through which plants undertake the gas exchange necessary for photosynthesis and respiration. The degree of effect depends upon the ease with which the particulates will settle on the plant's structure.
- If the particulate is chemically reactive, it may adversely affect vegetation, soil or species present in surface waters.

Secondary

- Earlier mortality in elderly patients with chronic pulmonary and coronary conditions. Increased respiratory illnesses and asthmatic symptoms (EPAQS, 1995b). Increased illnesses and required treatment will draw on the resources of health services (Cifuentas and Lave, 1993).

Indirect

- Air pollution in populated areas is a serious public concern (Department of the Environment, Transport and the Regions, 1998a; Scottish Office 1991).

Cumulative

- *No cumulative effects identified.*
- To ensure the greatest benefits to the population as a whole the UK Expert Panel on Air Quality Standards (EPAQS) has recommended reducing overall particulate levels.
- Total UK emissions of PM_{10} are estimated at 263,000 tonnes. The main contributors are power stations (15%), domestic (14%), road transport (diesel) (19%), mining and quarrying (11%). The Extraction and Distribution of fossil fuels produces a negligible amount by comparison (EPAQS, 1995b).

Odour

IMPACTS

Direct

- A significant proportion of total complaints to local authorities is about odour. For the year 1996/97, the Chartered Institute of Environmental Health reports that there were 15,264 complaints of smell from industrial processes in England & Wales. It is the handling, storage and treatment of raw waste material that gives rise to difficult odour control problems (NSCA, 1998).
- Public annoyance from the combined effect of odour intensity, character and overall acceptability.
- There are a wide variety of health impacts associated with odour due to the variety of atmospheric pollutants that may cause it. Impacts range from headaches caused by an odour's offensiveness to aggravating bronchitis and asthma.

Secondary

- Odour may be classified as a statutory nuisance if it is prejudicial to health or a nuisance.

Indirect

- *No indirect impacts identified.*

Cumulative

- Longer-term health effects include chronic respiratory diseases and cancers.

6.3.2.5 *Society*

Social Interaction

IMPACTS

Direct

- Generation of employment and income.
- Increased wage levels for individuals.
- *Improvement in local infrastructure and skill base.*
- Encouragement of migration into an area.
- Worker Mortality.

Secondary

- The *Socio-Economic Multiplier Effect* from increased employment in an area, will bring both beneficial and adverse impacts.
- Generation of support industries and indirect employment and income.
- Area enhancement will occur as operators support community initiatives that effectively contribute to self-management and an understanding of interdependence (Santa, 1998).
- Expansion of local services to meet project objectives – waste management facilities; buildings or healthcare facilities; training; transportation routes; recreational facilities; community centres.
- Health effects from discharges and emissions (these are discussed in detail in the environmental aspects themselves). Increased local risk from social diseases.
- Shift of employment from traditional to non-traditional labour; destabilisation of the purchasing power of locals by paying higher prices or consuming a larger proportion of the locally needed resources; strain on local services and resources (Jones et al., 1996).

Indirect

- Land taken for facilities; new improved access to rural and/or remote areas; accidental emissions and discharges (these are discussed in detail in the environmental aspects themselves); use of natural resources (water, timber, sand, gravel); disruption of habitats or fishing areas; influence on land use and tenure.
- *Changes in crime violation levels and structure.*
- Individuals are willing to pay to combat the adverse impacts that can arise from economic development, which include traffic congestion, noise and minor crime violations, and promote a demand for low-income housing (Linberg, 1997).
- The European public have since the late 1980s considered 'the environment' as a very important political problem; more so than the markets and inflation, and only less so than unemployment (DG Information, 1988).

Cumulative

- Economic rent to government in the form of royalties and taxes.
- Changes *in the quality of life*: lifestyles; community cohesion; patterns and structures of community and family life; attitudes and behaviour; perceptions of risk; distribution of powers.
- Cultural property changes.
- Possibility that the activity may cease (depleted reserves) bringing a 'bust' threat to a now dependent local economy.

6.3.3 Prioritisation of Environmental Aspects

6.3.3.1 Risk Assessment

Activity	Environmental Aspect	Environmental Burden	Impact Severity	Frequency	Risk Indice
Reservoir Management	Presence	Injection Facility (average fuel consumption is 2.5 te/day*): Exclusion Zone 0.79 km^2	1	5	5
	Injection of Waste into Formation	Slurry Handling Capacity 300 bbl/hr (1-1.5 te seawater/te dry weight cuttings)	1	5	5
	Hydrocarbons Released to Sea	Escape of waste to seabed surface	3	2	6
	Introduction of Foreign Species from Ballasting	Not Quantifiable	2	1	3
	Injection of Water into Formation*	Variable (Order of Magnitude: 10^5 STB/day)	1	5	5
		Sulphate Reducing Bacteria Biocide (D): (20 te/year - water injection)	1	4	4
	Sewage & other Facility Wastes	Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person;	2	5	10
	Disturbance	Life of field for water injection facilities; Cuttings injection facilities 100te/day	1	4	4
	CO_2	8 te/day	3	5	15
	CO	0.02 te/day	2	5	10
	Oxides of nitrogen	0.02 te/day	3	5	15
	SO_2	0.01 te/day	3	5	15
	CH_4	Negligible	1	5	5
	VOC	Negligible	1	5	5
	Particulates	No data identified	-	-	
	Social Interaction	(2 individuals per shift for cuttings re-injection facility) No other data identified.	nq	nq	nq
		Fishing Industry	2	5	10
* Energy required to locally re-inject cuttings is 4,540 GJ/1000 hours (45.4 GJ/te diesel fuel) (ERM, 2000); the remote reinjection of cuttings will require energy to transport cuttings as well as that required for their disposal.					
Seismic Surveying	Seabed Disturbance	No known disturbance	-	-	-
		Disturbance predicted if OBC used throughout block area	2	5	10
	Persistent Waste to Sea or Land	Special Waste: >5 te	3	5	15
	Disturbance	2 months/100 km^2	1	4	4
	Sound in the Water	222 dB rel 1μPa @ 1m – Shot at 25 m intervals	3	5	15
		Delay P(0.1): Out of 174 gun starts ups, 19 resulted in operation delay**			
	Sound in the Air	No data identified	1	5	5
	Hydrocarbons Released to Sea	Variable	3	5	15
	Introduction of Foreign Species from Ballasting	Not Quantifiable	2	1	3
	Chemical Discharges	No data identified	-	-	-
	Sewage & other Facility Wastes	Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person;	2	5	10
	CO_2	5760 te/60 days*	3	5	15
	CO	14.4 te/60 days	2	5	10
	Oxides of nitrogen	106.2 te/60 days	3	5	15
	SO_2	7.2 te/60 days	3	5	15
	CH_4	Negligible	1	5	5
	VOCs	No data identified	-	-	-
	Particulates	No data identified	-	-	-
	Social Interaction	30-40 people at sea	nq	nq	nq
		Fishing Industry	2	5	10
* Seismic vessel requires 30 tonnes of fuel/day					
** Data from field trials of passive acoustic monitoring offshore (Gordon et al., 2000).					

Activity	Environmental Aspect	Environmental Burden	Impact Severity	Frequency	Risk Indice
Drilling	Presence	2 semi-submersibles (average fuel consumption of semi-submersibles is 10 te/day); Exclusion Zone 0.79 km^2	1	5	5
	Discharge of Solid Material	1770 tonnes (Average Well); 769 te/cuttings discharged directly to the seabed from tophole section/well; 1,001 te/cuttings discharged through the water column from bottomhole sections/well; 300 te/cement/well	2	5	10
	Heavy Metals	Barite source: <0.2ppm mercury; 12 ppm lead	2	5	10
	Seabed Disturbance (Anchoring)	0.003 km^2	1	5	5
	Persistent Waste to Sea or Land	<5 te/year Special Waste; Scrap metal: 20-35 te/year	3	5	15
	Disturbance	Average drilling time 80 days/well: Phase 1 80 days; Phase 2 900 days	1	4	4
	Sound in the Water	154 dB rel 1µPa @ 1m (10Hz-4kHz): Overall broadband levels do not to exceed local ambient levels beyond 1km	1	3	3
	Sound in the Air	No data available	-	-	-
	Hydrocarbons Released to Sea	Variable from spilt oil	4	5	20
	*Diesel Spill Frequency (drilling)***	<0.1te; 15; 0.0067	3	3	9
		0.1-<1 te; 17; 0.0076	3	3	9
		1<5; 7; 0.0031	3	3	9
		5-<25; 5;0.0022	3	3	9
		25-<50; 0; 0	-	-	-
		50+; 1; 0.0004	3	2	6
	*Diesel Spill Frequency (bunkering)***	<0.1te; 59; 0.0327	3	4	12
		0.1-<1 te; 44; 0.0243	3	4	12
		1<5; 16; 0.0088	3	3	9
		5-<25; 6; 0.0033	3	3	9
		25-<50; 0; 0	-	-	-
		50+; 0; 0	-	-	-
	*Blowout & Spillage Risk from Semi-submersible****	12,500 bbls of oil (worst case)	5	2	10
	Oil-based Muds	Variable total discharge per well to sea	4	5	20
	*Diesel Mud Spill Frequency***	*<0.1te; 9; 0.0040*	*3*	*3*	9
		0.1-<1 te; 27; 0.0121	*3*	*4*	12
		1<5; 65; 0.0290	*3*	*4*	12
		5-<25; 62; 0.0277	*3*	*4*	12
		25-<50; 12; 0.0054	*3*	*3*	9
		50+; 8; 0.0036	*4*	*3*	12
	Water-based Muds	Variable total discharge per well to sea	1	5	5
	Synthetic-based Muds	Variable total discharge per well to sea	4	5	20
	Introduction of Foreign Species from Ballasting	Not Quantifiable	2	1	3
	Chemical Discharges	Principally completion fluid (amount variable)	1	4	4
	Sewage & other Facility Wastes	Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person (full sewage treatment assumed);	2	5	10
	Brines	Variable total discharge per well to sea	1	5	5
	Heated Water	Variable total discharge per well to sea	1	5	5
	CO_2	9140 te (average per well from power generation*); 980 te (average from well testing and completion)	3	5	15
	CO	30 te (average per well from power generation)	2	5	10
	Oxides of nitrogen	115 te (average per well from power generation)	3	5	15

Activity	Environmental Aspect	Environmental Burden	Impact Severity	Frequency	Risk Indice
	SO_2	120 te (average per well from power generation)	3	5	15
	CH_4	0.3 te (average per well from power generation)	3	5	15
	CFCs/CBCs/HCFCs (Halons)	-	-	-	-
	VOCs	3.7 te (average per well from power generation)	3	5	15
	H_2S	*Dependent upon formation*	3	5	15
	Particulates	2 te/100 bbl oil	2	5	10
	Odour (Where cuttings are brought ashore)	Not Quantifiable: specialist panel employed to decide whether odour is a statutory nuisance	3	5	15
	Social Interaction	70-100 people at sea (semi-submersibles remain permanently at sea)	nq	nq	nq
		Fishing Industry	2	5	10
* Average fuel consumption on semi-submersibles is 10 tonnes per day. An average well is considered to be drilled with WBM and take 80 days.					
** Diesel Spill Frequency Calculated from PON 1 returns to the UK DTI; 1982-1997 (ERT, 1998) - Statistics are presented as Spill Size (tonnes); Number of Spills; Number of per Wells Drilled (except the Diesel Spills during Drilling where this number is per Facility Year)					
*** Blowout risk p(0.00005). Blowout risk with oil spillage 10-4 - 10-5 (Sharples, 1992).					
Production	Presence	Steel Platform	1	5	5
	Discharge of Solid Material	Variable total discharge per well to sea; Minimal risk of sand production if any formation sand is cemented throughout a well.	1	5	5
	Persistent Waste to Sea or Land	Special Waste: 25-50 te/year; 100-400 of Scrap Metal; Other: 1-2kg/person daily	3	5	15
	Low Specific Activity Scale	2 bbls of $CaCO_3$ scale slurry	3	5	15
	Disturbance	Installation, commissioning and operating platform: Exclusion Zone 0.79 km^2	1	4	4
	Sound in the Water	Production Platform Noise: strongest tones predicted to be between low frequencies of 4-39 Hz. Peak sound spectrum levels 100-500 Hz. No source level estimates.	1	5	5
	Sound in the Air	Helicopter: 90-110 dB rel 1μPa @ 1m; 1-8 kHz	1	5	5
	Hydrocarbons Released to Sea	Variable total discharge per well to sea	4	5	20
	Introduction of Foreign Species from Ballasting	Not Quantifiable	1	1	1
	Chemical Discharge	Produced Water*	2	4	8
	Sewage & other Facility Wastes	Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person (full sewage treatment assumed)	2	5	10
	Heated Water	Variable total discharge per well to sea	1	5	5
	CO_2	144,000 te/year (average) from power generation**; 385 te/10 days per well fracturing intervention***; 225 te/5 days per well wireline intervention; 630 te/year in flared gas****; 5 te/te of installed and commissioned structure*****	3	5	15
	CO	373.5 te/year (average) from power generation; 1.3 te/10 days per well fracturing intervention; 1.3 te/5 days per well wireline intervention; 2 te/year in flared gas	2	5	10
	Oxides of nitrogen	1638 te/year (average) from power generation; 5te/10 days per well fracturing intervention; 5 te/5 days per well wireline intervention; 0.3 te/year in flared gas; 0.02 te/te of installed and commissioned structure	3	5	15

Activity	Environmental Aspect	Environmental Burden	Impact Severity	Frequency	Risk Indice
	SO_2	180 te/year (average) from power generation; 0.7 te/10 days per well fracturing intervention; 0.7 te/5 days per well wireline intervention; negligible te/year in flared gas; 0.02 te/te of installed and commissioned structure	3	5	15
	CH_4	4.95 te/year (average) from power generation; 4 te/year in flared gas	3	5	15
	CFCs/CBCs/HCFCs (Halons)	Not Quantifiable (minor fugitive emissions do occur)	3	5	15
	VOCs	54 te/year (average) from power generation; 0.2 te/10 days per well fracturing intervention; 0.2 te/5 days per well wireline intervention; 0.5 te/year in flared gas	3	5	15
	H_2S	Hydrogen Sulphide Scavenger*	3	5	15
	Particulates	2% of total oil for flaring	2	5	10
	Social Interaction	50-300 people	nq	nq	nq
		Fishing Industry	2	5	10
* The chemicals used in to maintain the integrity of the production, water injection, and oil and gas treatment systems are not all discharged into the sea, the greatest amounts are lost to the reservoir.					
** Assumes that the average consumption of diesel for 45 MW power generation requirements is 45,000 te/year.					
*** Assumes that well fracturing requires an intervention of the well for a maximum period of 10 days.					
**** Under normal operating conditions, assumes 0.6 tonnes of purge and pilot gas per day will be flared.					
***** Calculated from dismantling operations and the manufacture of platform iron ore emissions detailed in the evaluation of decommissioning options for the Heather platform (Side & Kerr 1997).					
Pipeline Transportation	Presence	Pipeline length will be variable	1	5	5
	Discharge of Solid Material	Rockdumping	1	5	5
	Heavy Metals	Anodes corrode by 2.5%-3%/ year	2	5	10
	Seabed Disturbance	Localised & temporary along route	1	5	5
	Persistent Waste to Sea or Land	Special & Scrap Waste: <5 tonnes; Other: 1-2kg/person daily	3	5	15
	Disturbance	Working vessels & pipeline route	1	4	4
	Sound in the Water	No data available	-	-	-
	Sound in the Air	No data available	-	-	-
	Hydrocarbons Released to Sea	Variable total discharge per well to sea	4	5	20
		Pipeline accidents	5	2	10
	Introduction of Foreign Species from Ballasting	Not Quantifiable	1	1	1
	Chemical Discharges	Very small amounts; e.g.1 te Inhibitor *D*	1	5	5
	CO2	75 te/ km of pipeline (installation and commissioning)	3	5	15
	CO	0.3 te/ km of pipeline (installation and commissioning)	2	5	10
	Oxides of nitrogen	0.9 te/ km of pipeline (installation and commissioning)	3	5	15
	SO2	0.1 te/ km of pipeline (installation and commissioning)	3	5	15
	CH4	Negligible	3	5	15
	VOCs	0.1 te/ km of pipeline (installation and commissioning)	3	5	15
	Particulates	No data identified	-	-	-
	Social Interaction	20-50 people directly involved with pipeline installation and commissioning	nq	nq	nq
		Fishing Industry	2	5	10

Activity	*Environmental Aspect*	*Environmental Burden*	*Impact Severity*	*Frequency*	*Risk Indice*
Tanker Transportation	Disturbance	Shuttle tanker route (average fuel consumption 3.6 te diesel/10 km)	1	4	4
	Sound in the Water	170 - 200 dB rel 1μPa @ 1m (5Hz-430Hz)**	3	5	15
	Sound in the Air	No data identified	-	-	-
	Hydrocarbons Released to Sea	Mean loss of crude from ship-based transportation is 0.19% of total transported*.	4	5	20
		Tanker accidents	4-5	4	16-20
	Introduction of Foreign Species from Ballasting	Not Quantifiable	1	1	1
	Sewage & other Facility Wastes	Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person;	2	5	10
	CO2	11.5 te/10 km	3	5	15
	CO	0.02 te/10 km	2	5	10
	Oxides of nitrogen	0.21 te/10 km	3	5	15
	SO2	0.01 te/10 km	3	5	15
	CH4	Negligible	3	5	15
	VOCs	Negligible	3	5	15
	Particulates	No data identified	-	-	-
	Social Interaction	4-15 people are employed	nq	nq	nq
		Fishing Industry	1	2	2

* Institute of Petroleum, 1997.

** includes supertankers

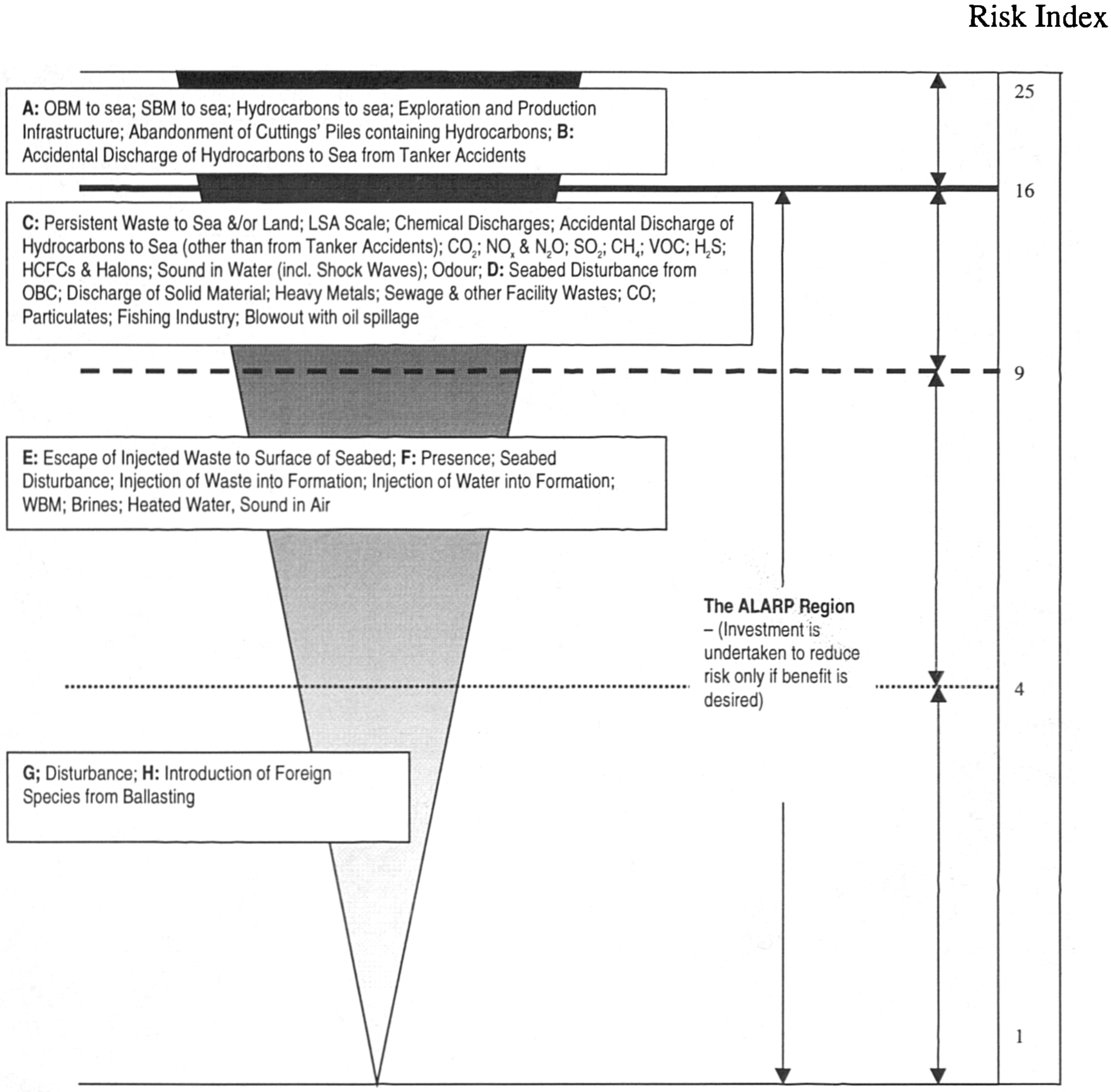
*** Tanker accident with oil spillage 10-2 - 10-3 (Sharples, 1992)

Activity	*Environmental Aspect*	*Environmental Burden*	*Impact Severity*	*Frequency*	*Risk Indice*
Decommissio-ning	Heavy Metals	Anodes corrode by 2.5%-3%/ year: 20-25 years Lifetime	2	5	10
	Seabed Disturbance	Vicinity of Platform: Exclusion Zone 0.79 km^2	1	5	5
	Persistent Waste to Sea or Land	Structures vary from <10,000 te - >50,000 te: Steel structures (after anodes mass consumed) have a lifetime of 150 years (corrosion - collapse)	4	5	20
	Low Specific Activity Scale	<1 te	3	5	15
	Disturbance	Working vessels & residual structure	3	5	15
	Sound in the Water	Shock wave (explosion)	4	5	15
	Sound in the Air	No data identified	-	-	-
	Hydrocarbons Released to Sea	Variable total discharge from pipeline flushing to sea	4	5	20
	Oil-based Muds	Cuttings' Pile Disturbance (size: variable)	4	5	20
	Introduction of Foreign Species from Ballasting	Not Quantifiable	1	2	2
	Chemical Discharges	Risk of releasing unknown quantities and types (particularly if disturbing cuttings' piles)	3	5	15
	Sewage & other Facility Wastes	>2000 te of Marine growth; Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person (full sewage treatment assumed);	1	5	5
	CO_2	4.55 te/te decommissioned structure**	3	5	15
	CO	Unquanitified for total operation; 0.5 te/ well plugging and abandonment (3 days)	2	5	10
	Oxides of nitrogen	0.04 te/te decommissioned structure	3	5	15
	SO_2	0.02 te/te decommissioned structure	3	5	15
	VOC	Unquanitified for total operation;Negligible te/ well plugging and abandonment (3 days)	3	5	15
	Particulates	No data identified	-	-	-
	Odour	Not Quantifiable (Rotting Marine Growth)	3	5	15
	Social Interaction	100-200 directly involved	nq	nq	nq
		Fishing Industry	2	5	10

* Plastics, rubber: 1-5 te; asbestos, mineral wool: 1-5 te

** Emissions are estimated on a tonnage to be decommissioned basis from calculated total emission values proposed for total removal and of the Heather Platform by Side & Kerr, 1997.

6.3.3.2 Prioritised Environmental Aspects



6.3.4 Allocation of monetary value to environmental aspects

6.3.4.1 Factors affecting the Environmental Damage Costs

Environmental Aspect	*Environmental Impact*	*Environmental Change*	
		Type of Environmental Change	***Factor(s) affecting Level of Environmental Change***
Solid Materials			
Presence	Visual Eyesore; Marine Growth on Structure and Temporary Wildlife Haven; Temporary Exclusion Zone	Coastal Property Value; Number of Visits to Park; New Species; Effect on Biodiversity; Effect on Fishery Catch	Development Design;Duration of Activity; Coastal Land Use; Depth and type of Substrate; Location; Distribution of Commercial Fish Breeding and Spawning Locations; Fish Migratory Routes
Discharge of Solid Material	Temporary Light Inhibition; Smothering of Sessile Organisms and Ecosystems	Habitat Loss; Species Loss	Quantity and Discharge Rate of Material; Sea State; Type and Importance of Ecosystem to Other Users; Quantity and Discharge Rate of Material; Sea State; Type of Species
Heavy Metals	Toxic Effects to Organisms; Bioaccumulation and biomagnification in food webs; Health Effects to Homo sapiens	Species Loss; Effect on Human Health	Success of Uptake through Food Chain; Dose/Exposure Response Relationship
Seabed Disturbance	Mortality and Displacement of Species; Recolonisation	Species Loss; Habitat Loss & Creation	Presence of Marine Fauna &/or Flora; Type of Ecosystem
Persistent Waste to Sea or Land	Mortality and Displacement of Species; Recolonisation	Species Loss; Habitat Loss & Creation	Type of Waste; Hydrodynamic Forces; Exposure of Species to High Risk Wastes
LSA Scale	Health Effects to Homo sapiens	Health Effects	Exposure Level
Injection of Waste into Formation	Formation Damage	*Release of Waste into Environment (type of change dependent on waste)*	Fracture Propogation Risk
Energy			
Disturbance	Nuisance; Animal Feeding and Breeding Disruption; Loss of Species in a Given Area; Interruption and Delay in Animal Migrations	Complaints; Species Loss	Time and Duration of Activities; Distance From Populated Areas; Type of Species; Breeding and Feeding Areas; Migratory Routes; Level of Disturbance
Noise in Water and Air (incl. Shock Waves)	Injury or Death of Species; Animal Feeding and Breeding Disruption; Interruption and Delay in Animal Migrations; Loss of Species in a Given Area; Global Disruption to Cetacean Evolution	Species Loss	Type of Species & Public Concern; Breeding and Feeding Areas; Migratory Routes
Liquid Discharges			
Hydrocarbons released to Sea	Toxic Effects to Organisms; Ecosystem Degradation; Bioaccumulation and biomagnification in food webs; Health Effects to Homo sapiens	Species Loss; Habitat Loss; Effect on Human Health	Quantity and Type of Oil; Sea State; Water Depth; Availability of Microbes to Biodegrade Oil; Type of Species & Public Concern; Type and Importance of Ecosystem to Other Users; Success of Uptake through Food Chain; Dose Response Relationship
Oil-based Muds	Toxic Effects to Organisms; Ecosystem Degradation; Bioaccumulation and biomagnification in food webs; Health Effects to Homo sapiens	Species Loss; Habitat Loss; Effect on Human Health	Quantity and Discharge Rate of Oil; Type of Oil; Sea State; Water Depth; Availability of Microbes to Biodegrade Oil; Availability of Dissolved Oxygen on the Seabed; Type of Species & Public Concern; Type and Importance of Ecosystem to Other Users; Success of Uptake through Food Chain; Dose Response Relationship
Synthetic-based Muds	Toxic Effects to Organisms; Ecosystem Degradation	Species Loss; Habitat Loss; Effect on Human Health	Quantity and Discharge Rate of Chemical(s); Type of Chemical; Toxicity of Chemical Cocktails; Sea State; Water Depth; Type of Species & Public Concern; Type and Importance of Ecosystem to Other Users; Success of Uptake through Food Chain; Dose Response Relationship

Environmental Aspect	*Environmental Impact*	*Environmental Change*	
		Type of Environmental Change	***Factor(s) affecting Level of Environmental Change***
Water-based Muds	Toxic Effects to Organisms; Ecosystem Degradation	Species Loss; Habitat Loss; Effect on Human Health	Quantity and Discharge Rate of WBMs; Type of Chemicals used; Toxicity of Chemical Cocktails; Sea State; Water Depth; Type of Species & Public Concern; Type and Importance of Ecosystem to Other Users; Success of Uptake through Food Chain; Dose Response Relationship
Introduction of Foreign Species from Ballasting	Toxic Effects to Organisms; Domination of Foreign Species over Indigenous Species in Ecosystem; Biodiversity Decline	Species Loss; Habitat Loss	Sensitivity of Ecosystem to Foreign Species; Foreign Species Colonisation Success; Type and Importance of Ecosystem to Other Users
Chemical Discharges	Toxic Effects to Organisms; Bioaccumulation and biomagnification in food webs; Health Effects to Homo sapiens	Species Loss; Habitat Loss; Effect on Human Health	Quantity and Type of Chemical; Toxicity of Chemical Cocktails; Sea State; Water Depth; Type of Species/Chemicals & Public Concern; Type and Importance of Ecosystem to Other Users; Success of Uptake through Food Chain; Dose Response Relationship
Sewage and Other Facility Wastes	Ecosystem Degradation	Species Loss; Habitat Loss; Effect on Human Health	Type of Treatment; Availability of Free Chlorine; Sea State; Water Depth; Availability of Microbes to Specific Chemicals; Type of Species & Public Concern; Type and Importance of Ecosystem to Other Users; Success of Uptake through Food Chain; Dose Response Relationship
Brines	Ecosystem Degradation	Loss of Species of Plankton	Quantity; Discharge Rate; Salt Content; Water Depth; Hydrodynamic Forces
Injection of Waste into Formation	Formation Damage	Release of Waste into Environment (type of change dependent on waste)	Fracture Propogation Risk
Heated Water	Increased Growth in Organisms; Species Mortality	Loss of Species & Introduction of Others	Temperature, Quantity and Discharge Rate of Discharge; Water Depth; Type of Species; Type and Importance of Ecosystem to Other Users
Atmospheric Emissions			
Carbon Dioxide	Enhanced Photosynthesis Rates; Temperature Increase - Climate Change and Sea Level Rise; Health Effects to Homo sapiens	Species Loss; Habitat Loss; Crop Productivity; Housing Loss & Prices; Finding Homes for or Repatriation of Refugees; Effect on Human Health	Quantity and Discharge Rate of CO2; Ambient Concentration of CO2 and other Global Warming Gases; Atmospheric Lifetime; Point of Discharge; Public Concern
Carbon Monoxide	Health Effects to Homo sapiens	Effect on Human Health	Quantity and Discharge Rate of CO; Exceedance of Critical Loads; Atmospheric Lifetime
Oxides of Nitrogen	Acid Rain; Ecosystem Degradation; Temperature Increase - Climate Change and Sea Level Rise; Health Effects to Homo sapiens	Species Loss; Habitat Loss; Crop Productivity; Effect on Human Health; Housing Loss & Prices; Finding Homes for or Repatriation of Refugees	Quantity and Discharge Rate of Oxides of Nitrogen; Ambient Concentration of Oxides of Nitrogen and other Global Warming Gases; Atmospheric Lifetime; Exceedance of Critical Loads; Public Concern
Sulphur Dioxide	Acid Rain; Ecosystem Degradation	Species Loss; Habitat Loss; Crop Productivity; Effect on Human Health	Quantity and Discharge Rate of SO2; Exceedance of Critical Loads; Atmospheric Lifetime; Public Concern
Methane	Temperature Increase - Climate Change and Sea Level Rise; Health Effects to Homo sapiens	Species Loss; Habitat Loss; Crop Productivity; Effect on Human Health; Housing Loss & Prices; Finding Homes for or Repatriation of Refugees	Quantity and Discharge Rate of CH4; Ambient Concentration of CH4 and other Global Warming Gases; Atmospheic Lifetime; Public Concern

Environmental Aspect	*Environmental Impact*	*Environmental Change*	
		Type of Environmental Change	***Factor(s) affecting Level of Environmental Change***
Chlorofluoro/bromo carbons & other halons	Ozone Depletion; Temperature Increase - Climate Change and Sea Level Rise	Species Loss; Habitat Loss; Crop Productivity; Pest Control; Effect on Human Health; Housing Loss & Prices; Finding Homes for or Repatriation of Refugees	Quantity and Discharge Rate of CFCs & Halons; Atmospheric Lifetime; Public Concern
Volatile Organic Compounds	Toxic Effects on Organisms; Photochemical Smog; Enhanced Levels of Photosynthesis; Ozone Depletion;Temperature Increase - Climate Change and Sea Level Rise;Health Effects to Homo sapiens	Species Loss; Habitat Loss; Crop Productivity; Pest Control; Effect on Human Health; Housing Loss & Prices; Finding Homes for or Repatriation of Refugees	Quantity and Discharge Rate of VOC; Ambient Concentration of VOC and other Global Warming Gases; Atmospheric Lifetime; Exceedance of Critical Loads; Public Concern
Dihydrogen Sulphide	Toxic and Fatal Effects on Organisms; Acid Rain; Ecosystem Degradation	Species Loss; Habitat Loss; Crop Productivity; Effect on Human Health	Quantity and Discharge Rate of H2S; Exceedance of Critical Loads; Atmospheric Lifetime; Public Concern
Particulates	Health Effects to Homo sapiens; Ecosystem Degradation	Loss of Species; Loss of Habitats; Effect on Human Health	Particulate Size; Quantity and Discharge Rate of Particulates; Ambient Concentration of Oxides of Nitrogen and other Global Warming Gases; Atmospheric Lifetime; Exceedance of Critical Loads; Public Concern
Odour	Health Effects to Homo sapiens	Nuisance Level; Effect on Human Health	Odour Intensity, Character & Overall Acceptability
Society			
Social Interaction	Social Concerns; Social Changes; Education Quality Improvement; Health Facilities; Generation of Income; Payment of Taxes and Royalties; Institutional Strengthening and Maintaining Communities' Cultural Heritage	Public Outrage; Long-term Welfare of Communities (Local Socio-Economic Multiplier Effect); Crime Levels; Cost of Living; Housing Costs; Social Work	Level of Existing Economic Development; Availability of Local Workforce; Availability of Local Materials; Annual Changes in Inflation; Existing Levels of Crime; Housing Market; Amount of Social Work; Politcial Stability

6.4 STAGE 3 – ENVIRONMENTAL RISK MITIGATION SYSTEM ANALYSIS

6.4.1 Comparison of the environmental risk mitigation cost incurred by the operator against the value of the environmental damage potentially incurred by society for proposed environmental risk mitigation systems, and identification of a system that is both eco-efficient and cost effective

Impact Significance	Environmental Aspect	Environmental Burden	Environmental Damage Costs £(2000)	Project Parameters (worst case)	Environmental Damage £(2000) Low Mitigation 'Ebham' (illegal operation - licence refused)
A	*Oil-based Muds*	586 te/ Average per well for disposal.	14-4,582 for ecological habitat/ te oil discharged/spilt to sea (3.1.2) Values incoporate temporal and spatial variations	1 Appraisal Well; 9 Production Wells; 14 Injector Wells - 586 te OBM discharged to sea; Total Discharge 14,064 te; Total Damage to the Environment 84,384-64,441,248: 5% & 95% percentile.	21414515.32
			401-3,218 or ecological habitat/te oil spilt to a waterway (3.1.3) Values incoporate temporal and spatial variations		
			6-23 for ecological habitat/te oil discharged/spilt to sea (3.1.7)		
	Synthetic-based Muds	Designed as Environmental Mitigation Measure - 600 tonnes average discharge/well.	6-23 for ecological habitat/te SBM discharged to sea (3.1.7)	*See Mitigation 1*	
			301-1064/year for uncontaminated water/household affected (3.3.2)		
	Hydrocarbons to Sea	Variable discharges of oil from facilities. Produced Water Volume 75,000 bbl/day. 15 ppm oil in water for vessel discharges (Seismic); 15 ppm oil in water for facility drainage water and 40 ppm oil in water from cuttings treatment (Drilling),Oil in Produced Water 40 ppm; 15 ppm oil in water for vessel discharges (Pipeline Construction), 40 ppm oil in water for decommissioned pipeline flushing (Decommissioning).	14-4,582 for ecological habitat/ te oil discharged/spilt to sea (3.1.2) Values incoporate temporal and spatial variations	Oil content in produced water discharged to sea after primary treatment - 50ppm. Total oil discharged every year 180 te. Total Damage to the Environment: 12,960-9,897,120; 5% & 95% percentile.	1808417.796
			401-3,218 or ecological habitat/te oil spilt to a waterway (3.1.3) Values incoporate temporal and spatial variations		
			6-23 for ecological habitat/te oil discharged/spilt to sea (3.1.7)		
	Abandonment of Cuttings' Piles	Variable Form (dependent upon drilling fluids used and hydrodynamic forces) OBM cuttings' piles for Field X would be <10 m height and >15 m diameter. Water contained in the cuttings pile and uplifted during cuttings treatment has oil content that has to be reduced prior to discharge. 733 tonnes of water assumed for each OBM cuttings pile. Any discharges of oil in water must not exceed 40 ppm during cuttings pile retrieval.	14-4,582 for ecological habitat/ te oil discharged/spilt to sea (3 1.2) Values incoporate temporal and spatial variations	*Already assessed above under OBM however this is an important consideration during the acquisition of mature assets*	-
			401-3,218 or ecological habitat/te oil spilt to a waterway (3.1.3) Values incoporate temporal and spatial variations		
			6-23 for ecological habitat/te oil discharged/spilt to sea (3.1.7)		
B	*Accidental Discharge of Hydrocarbons to Sea from Tanker Accidents*	Tanker accident with oil spillage 10^{-3} - 10^{-5}	*See above*	*The Field Development programme recommends a pipeline system due to the local available infrastructure to maximise NPV.*	-

Impact Significance	Environmental Aspect	Environmental Burden	Environmental Damage Costs £(2000)	Project Parameters (worst case)	Environmental Damage £(2000) Low Mitigation 'Ebham' (illegal operation - licence refused)
C	*Persistent Waste to Land &/or to Sea*	Special Waste >5 te/year (Seismic), <5 te/year Special Waste (Drilling); Scrap metal: 20-35 te/year (Drilling); Special Waste: 25-50 te/year; 100-400 of Scrap Metal/year (Production); Special & Scrap Waste: <5 tonnes/year (Pipeline); 37,000 te Structure. (2 months Seismic Survey; 1,920 Drilling Days; 2 months Pipeline Commissioning and Installation; Life-of field 12 years)	14-30/ te special and scrap waste (3.1.7)	Total amount of waste discharged to the sea: 42,565 te. Total damage to the environment: 595,911-1.3 million; 5% & 95% percentile.	[illegible]
	LSA Scale	2 bbls of $CaCO_3$ scale slurry (Production) + <1 te $CaCO_3$ scale slurry (Decommissioning)	30/te special waste	Assuming that the 7 bbls of slurry equate to 1 te; Total discharged to sea: 0 43 te. Total damage to the environment 13	13
	Chemical Discharges (other than drilling fluids)	17 te/ Average Completion Fluid per Well (Drilling), Produced Water* (Corrosion Inhibitor - D 90 te/year; Scale Inhibitor - D 90 te/year, Slick Dispersant C 3 te/year) (Production), 1 te Inhibitor D (Pipeline Transportation)	6-23 for ecological habitat/te chemical mixture discharged to sea (3.1.7)	Total discharge of chemicals to sea: 201 te, Total damage to the environment: 1,206-4,62;: 5% & 95% percentile.	[illegible]
			301-1064/year for uncontaminated water/household affected (3.3.2)	*Offshore field development potable water is unlikely to be affected.*	
	Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents)	Maximum 3 te Leakage of Kerosene/Ruptured Cable (Seismic); Diesel Spill Frequency and Mud Spill Frequency (Drilling); Diesel Spill Frequency (Bunkering); Pipeline Accidents; (includes blowout risk)	14-4,582 for ecological habitat/ te oil discharged/spilt to sea (3.1.2) Values incorporate temporal and spatial variations	Total expected damage to the environment from historical and modelled data: 411-312,185 (includes the risk of oil-based discharges from OBM usage); 5%-95% percentile. *(Offshore Natural Dispersion (Do-Nothing) with potential onshore damage - 1.5% - 2.3% Drop in Share Value)*	[illegible]
			401-3,218 or ecological habitat/te oil spilt to a waterway (3.1.3) Values incorporate temporal and spatial variations		
			6-23 for ecological habitat/te oil discharged/spilt to sea (3.1.7)		

Impact Significance	Environmental Aspect	Environmental Burden	Environmental Damage Costs £(2000)	Project Parameters (worst case)	Environmental Damage £(2000) Low Mitigation - 'Ebham' (illegal operation - licence refused.
	Carbon dioxide	5760 te/60 days (Seismic); 9140 te (average per well (24) from power generation) - 127,960te; 980 te (average from well testing and completion) 23,520 te; 144,000 te/year (average) from power generation (12 years) - 1.73 million te; 385 te/10 days per well fracturing intervention 9,240 te; 225 te/5 days per well wireline intervention - 5,500 te; 630 te/year in flared gas - 7,560 te; 5 te/te of installed and commissioned structure (37,000 te of steel) - 185,000 te; 75 te/ km of pipeline (installation and commissioning of 105 km of pipeline) - 7,875 te.	Direct Bequests: 13-55/ te; Research & Development: 28-92/te; Capital Investment: 34-87/te. (4.1.1) Average: 25-78/ te carbon dioxide emitted	Total Expected Emissions: 2.1 million te. Total damage to the environment 15.3 million - 453.6 million; 5% & 95% percentile.	[illegible]
			2-59/te carbon (7.3-216/te CO_2) emitted (4.1.2)		
	Oxides of nitrogen	106 2 te/60 days; 115 te (average per well from power generation) - 2760 te; 1.1 te (average from well testing and completion) - 26.4 te; 1638 te/year (average) from power generation - 19,656 te; 5te/10 days per well fracturing intervention - 120 te; 5 te/5 days per well wireline intervention - 120 te; 0.3 te/year in flared gas - 3.6 te; 0.02 te/te of installed and commissioned structure - 740 te; 0.9 te/ km of pipeline (installation and commissioning - 105 kms) - 94.5 te.	43-90/ any exceedence of an Air Quality Standard (4.3.1)	Total Emissions to air: 5609 te. Total Damage to the Environment: 241,187 17.7 million; 5% & 95% percentile.	[illegible]
			NO_x GWP (100 years) of 40: 1000-3158/ te oxides of nitrogen emitted (4.1.1)		

Impact Significance	*Environmental Aspect*	*Environmental Burden*	*Environmental Damage Costs £(2000)*	*Project Parameters (worst case)*	*Environmental Damage £(2000) Low Mitigation 'Ebham' (illegal operation - licence refused)*
			450 for Health Effects/te NO_2 emitted (include fatalities) (4.4.3)		
	Sulphur dioxide	7.2 te/60 days; 120 te (average per well from power generation) - 2880 te;18.6 te (average from well testing and completion) - 446.4 te; 180 te/year (average) from power generation - 2160 te; 0.7 te/10 days per well fracturing intervention - 20.3 te; 0.7 te/5 days per well wireline intervention - 20.3 te; negligible te/year in flared gas; 0.02 te/te of installed and commissioned structure - 740 te; 0.1 te/ km of pipeline (installation and commissioning) - 10.5 te.	2475 for Health Effects/te SO_2 emitted (include fatalities) (4.4.3)	Total Emissions to air: 6285 te. Total Damage to the Environment: 37,710 - 15.6 million; 5% & 95% percentile.	£038717.111
			8-23 for ecological habitat/te acidification damage (3.1.7)		
	Methane	0 3 te (average per well from power generation) - 7.2 te; 7.1 te (average from well testing and completion) - 170 4 te; 4 95 te/year (average) from power generation - 59 4 te; 4 te/year in flared gas - 48 te.	CH_4 GWP (100 years) of 21: 526-1579/ te methane emitted (4.1.1)	Total Emissions to air: 285 te. Total Damage to the Environment: 149,910 - 450,015; 5% & 95% percentile.	178,488
	Volatile Organic Compounds	3 7 te (average per well from power generation) - 88 8 te, 7.1 te (average from well testing and completion) - 170.4, 54 te/year (average) from power generation - 648 te; 0.2 te/10 days per well fracturing intervention - 4.8 te; 0.2 te/5 days per well wireline intervention - 4 8 te; 0.5 te/year in flared gas - 12 te; 0.1 te/ km of pipeline (installation and commissioning) - 10.5 te.	VOC GWP (100 years) of 11: 263-790/ te volatile organic acid emitted (4.1.1)	Total Emissions to air: 939 te. Total Damage to the Environment: 246,957 - 741,810; 5% & 95% percentile.	£82021,259
	Hydrogen disulphide	Removed using Hydrogen Sulphide Scavenger	489,344-617,783/ Statistical life which includes worker's compensation (5.4.1)	0	0
			2475 for Health Effects/te SO_2 emitted (include fatalities) (4.4.3)		
	CFCs, CBCs, HCFCs & and other halons	Fugitive Emissions from Production Platform (Not quantifiable without monitoring)	HCFC-124 GWP (100 years) of 480: Average: 11,975-37,241/ te HCFC-124 emitted (4.1.1)	nq	nq
			760-1,265/ lifetime avoidance of skin cancer (4.7.2)		
	Sound in Water	222 dB rel 1µPa @ 1m – Shot at 25 m intervals (Seismic); 154 dB rel 1µPa @ 1m (10Hz-4kHz) (Drilling); No source level estimates for Production; probability of delay: p(0.1)	11 (3.1.7) - 23 for marine mammal/ affected (2.3.1)	10% chance that a marine mammal will be affected at some level from disturbance to fatal injury or loss of pod (assumed 40 individuals). Total Damage to the Environment: 1-92; 5% & 95% percentile.	£5,481205.96

Impact Significance	Environmental Aspect	Environmental Burden	Environmental Damage Costs £(2000)	Project Parameters (worst case)	Environmental Damage £(2000) Low Mitigation 'Ebham' (illegal operation - licence refused.
	Odour	Oil-based Drill Cuttings onshore/ 2000 te of organic growth on structure	nq	nq	nq
D	*Seabed Disturbance from Ocean Bottom Cable (Seismic)*	2 months/100 km²	11 (3.1.7) - 23 for marine mammal/ affected (2.3.1)	nq	nq
	Discharge of Solid Material	645 tonnes of oil-based mud contaminated cuttings (Average Well; 1.1*Total amount of mud used), 300 te/cement/well (Drilling); Variable sand discharge per well	14-19/ te solid material damaging the environment (3.1.7)	Total Discharges to sea: 22,680 te. Total Damage to the Environment: 317,520 430,920; 5% & 95% percentile.	405,518
	Heavy Metals	Barite source <0.2ppm mercury; 12 ppm lead (Drilling). Anodes corrode by 2.5%-3%/ year discharging zinc into the sea (10,000 times lower than the lowest documented concentration for acute concentration), and 1,000 times lower than the lowest documented concentration for chronic concentration, 20-25 years Lifetime (Abandoned Pipeline and Structure)	301-1064/year for uncontaminated water (that includes heavy metals, organic compounds, oil and feacal coliform bacteria)/household affected (3 3 2)	nq	nq
	Sewage & other Facility Wastes	Deck and domestic waste: 5-15 kg/day/person; Sewage with a BOD of 1.1 kg/day/person (All Phases); 60 people (Seismic); 70-100 people at sea (semi-submersibles remain permanently at sea); 150 people (Production); 50 people directly involved with pipeline installation and commissioning	301-1064/year for uncontaminated water (that includes heavy metals, organic compounds, oil and feacal coliform bacteria)/household affected (3.3.2)	WTP values apply to inland and not for offshore waters	nq
	Carbon monoxide	14.4 te/60 days; 30 te (average per well from power generation) - 720 te; 5.4 te (average from well testing and completion) - 129.6 te; 373.5 te/year (average) from power generation - 4482 te; 1.3 te/10 days per well fracturing intervention - 31.2 te, 1.3 te/5 days per well wireline intervention - 31.2 te; 2 te/year in flared gas - 24 te; 0.3 te/ km of pipeline (installation and commissioning) - 31.5 te.	CO GWP (100 years) of 4: Average: 79-316/ te carbon monoxide emitted (4.1.1)	Total Emissions to air: 5464 te. Total Damage to the Environment: 431,656 1.7 million; 5% & 95% percentile.	1,041,259

Impact Significance	Environmental Aspect	Environmental Burden	Environmental Damage Costs £(2000)	Project Parameters (worst case)	Environmental Damage £(2000) Low Mitigation 'Ebham' (illegal operation - licence refused)
	Particulates	2% of total oil from well testing (Drilling) and flaring (Production). 98% combustion efficiency is assumed. Production Well Test 1: 8,000 bbl of oil/day (38 hours) - 34 te; Production Well Test 2: 20,500 bbl of oil/day (45 hours) - 104 te; Production Well Test 3: 19,500 bbl of oil/day (30 hours) - 66 te; Production Well Test 4: 15,000 bbl of oil - 41 te . Under normal operating conditions, 0.6 tonnes of purge and pilot gas per day will be flared producing 53 te of unburnt hydrocarbons (oil and associated gas) over 12 years.	189-756 for pollution damage/ te particulates emitted (4.8)	PM is a mixture of of sulphate, nitrate and other aerosols that are formed from SO2 and NOx emissions. Thus the damage caused from particulates is already partly accounted for in power generation. In this valuation unburnt hydrocarbons are also considered as particulates. Total Emissions to air and sea: 298 te. Total Damage to the Environment: 56,322 - 225,288; 5% & 95% percentile.	125282.0881
	Social Interaction	Fishing Industry (All Phases)	No data identified	nq	nq
	Blowout from oil spillage	Blowout risk with oil spillage 10^{4} - 10^{-5} from Semi-submersible 12,500 bbls of oil: *p*(0 00005)(modelled worst case) (Drilling)	14-4,582 for ecological habitat/ te oil discharged/spilt to sea (3.1.2) Values incoporate temporal and spatial variations	Total Discharges to sea: 1689 te. Total Damage to the Environment: 0.5 - 387; 5% & 95% percentile.	Calculated in *Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents)*
			401-3,218 or ecological habitat/te oil spilt to a waterway (3.1.3) Values incoporate temporal and spatial variations		
			6-23 for ecological habitat/te oil discharged/spilt to sea (3 1.7)		
E	*Escape of waste to surface (injected waste/produced water)*	Water or waste oilfield slurry (Reservoir Management)	*See above*	nq	nq
F	*Presence*	3D seismic survey· 10 streamers 2,400 m long - 100 km^2 for 2 months, 2 Semi-submersible drilling rigs (1 Appraisal, 9 Production wells and 14 Injector Wells drilled by same facility) - 1.58 km^2 (2 years); Production - 0 79 km^2 (12 years); Transportation facilities include· 45 km long 24" tie-in oil pipeline, 60 km long 18" tie-in	5,600/km^2/year (2.1.1)	Total occupied area value: 147,896.	nq
			Offshore facility - no economic impact on coastal developments or tourism identified		
	Seabed Disturbance	0.003 km^2 (Anchoring for Drilling Rigs); Localised & temporary along route (Pipeline Transportation); Vicinity of Platform during Decommissioning (Exclusion Zone 0.79 km^2)	5,600/km^2/year (2.1.1). Pipeline and left structures considered ecologically beneficial by some experts.	Total estimated damage: 4441	4441
			Offshore facility - no economic impact on coastal developments or tourism identified		
	Injection of Waste into Formation	A Mitigation Measure	Economic impact on nearby reservoir productivity (no reservoirs identified)	-	-
	Injection of Produced Water into Formation	A Mitigation Measure	*See above*	-	-

Impact Significance	*Environmental Aspect*	*Environmental Burden*	*Environmental Damage Costs £(2000)*	*Project Parameters (worst case)*	*Environmental Damage £(2000) Low Mitigation 'Ebham' (illegal operation - licence refused,*
	WBM	A Mitigation Measure - 1,599 tonnes average discharge/well (Drilling)	301-1064/year for uncontaminated water (that includes heavy metals, organic compounds, oil and feacal coliform bacteria)/household affected (3.3.2)	-	-
	Brines	480 te/ average per well (Drilling)	No data identifed	-	nq
	Heated Water	17500m³/day per well (Drilling)	No data identified	-	nq
	Sound in Air	Helicopter: 90-110 dB rel 1μPa @ 1m; 1-8 kHz (Production)	11 (3.1.7) - 23 for marine mammal/ affected (2.3.1)	nq	nq
G	*Disturbance*	Injection Facility: Exclusion Zone 0.79 km² (Reservoir Management); 2 months/100 km² (Seismic); 2 semi-submersibles: Exclusion Zone 1.58 km² (Drilling); Installation, commissioning and operating platform: Exclusion Zone 0.79 km² (Production); Working vessels & pipeline route.	11 (3.1.7) - 23 for marine mammal/ affected (2.3.1)	Total occupied area value: 147,896. *(Damage considered as loss of ecological value due to operators lack of any form of environmental management)*	147896
			5,600/km²/year (2.1.1)		
H	*Introduction of Foreign Species from Ballasting*	Not Quantifiable (All Phases)	Not quantifiable and considered negligible due to the localised nature of operations.	nq	nq
				Total Environmental Damage	254,408,571

Impact Significance	Environmental Aspect	Mitigation 'Khencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Khencer'	Mitigation 'Bencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Bencer'
A	***Oil-based Muds***	Use Environmentally Acceptable Synthetic-based Mud - 4.17 GBP million/well; Total 100.08 million (Cost of OBM is considered the same as using SBM. The savings, in the past, have been associated with the ability to discharge cuttings on site, and avoid the logistical difficulties, and potential liabilities of transporting the cuttings to shore for disposal)	0	0	Discharge to Sea <10g/kg oil on Dry Cuttings (Direct Thermal Desorption - 0.5% oil content of cleaned solids) - 156.25 GBP/te treated (hire + treatment) 3.5 te/hour. (Total Oil Discharged to Sea over 1,920 days of drilling 1548 te) Total Damage to the Environment: 9,288-7,092,936; 5% & 95% percentile.	2418750	434174.8585
	Synthetic-based Muds	N/A			N/A		
	Hydrocarbons to Sea	30 Hydrocyclones, split into two units, one for each separator stage - reduce oil in water content down to 15-35 ppm (throughput capacity: 100-2,500 bwpd) - 0.01 GBP/bwpd (Total Oil Discharged to Sea over 12 years 1509 te) Total Damage to the Environment: 9,053-6,913,322; 5% & 95% percentile.	3285000	5259658.354	30 Hydrocyclones, split into two units, one for each separator stage - reduce oil in water content down to 15-35 ppm (throughput capacity: 100-2,500 bwpd) - 0.01 GBP/bwpd (Total Oil Discharged to Sea over 12 years 1509 te) Total Damage to the Environment 9,053-6,913,322; 5% & 95% percentile.	3285000	1188716.382
		Monitoring Oil in Outfalls of Water - 30,000 GBP/outfall (capex); 900 GBP/year opex/outfall - 5 outfalls assumed	204000		6x5 Centrifuge System - reduce oil in water content down to 5-20 ppm (input: no solids removed by desanders to work efficiently - throughput 12,600 bwpd) - Capex 625,000 GBP; Opex 16200/month (Total Oil Discharged to Sea over 12 years 862 te) Total Damage to the Environment: 5,172-3,949,684; 5% & 95% percentile.	17746800	
					Monitoring Oil in Outfalls of Water - 30,000 GBP/outfall (capex); 900 GBP/year opex/outfall	204000	
					Onshore Waste Oil Recycling - 29 GBP/te	46.4	
	Abandonment of Cuttings' Piles	See Discharge of Solid Material	0		Capping - 3 million GBP/pile	72000000	23749.6
B	***Accidental Discharge of Hydrocarbons to Sea from Tanker Accidents***	N/A			N/A		

Impact Significance	Environmental Aspect	Mitigation 'Khencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Khencer'	Mitigation 'Bencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Bencer'
C	***Persistent Waste to Land &/or to Sea***	5612 te of special and scrap waste sent to Licenced Waste Disposal Operator - 150-180 GBP/te (& Facility Waste Control System for domestic waste (Incineration) - no data identified)	1010160	0	5612 te of special and scrap waste sent to Licenced Waste Disposal Operator - 150-180 GBP/te (& Facility Waste Control System for domestic waste (Incineration) - no data identified)	1010160	0
		Complete Removal of Facilities - 150 million -180 million GBP - 99.8% Recycling Efficiency assumed. Total Benefit to the Environment: 516964-1107780 and Total Damage to the Environment: 1036-2220.	180000000	-682922.4578	Complete Removal of Facilities - 150 million -180 million GBP	180000000	-427398.9232
				1839.303253			1943.123253
	LSA Scale	Handling and Disposal of NORM Oil and Gas Field Waste by Licenced Operator - 212 GBP/te	91.16	0	Disposal in Permanent Low-level Radioactive Waste Facility - 742 GBP/te	319.06	0
	Chemical Discharges (other than drilling fluids)	The chemicals used in to maintain the integrity of the production, water injection, and oil and gas treatment systems are not discharged directly into the sea, but transported to treatment and lost to the reservoir. It assumed that 10% are lost to the sea.	0	190.4268654	Implemenation of Environmental Management System to ensure that low toxicity Group E chemicals are used, where possible, in compliance with OCNS - 10,000 - 100,000 GBP/year. It assumed that 10% of chemicals are lost to the sea.	100000	272.9724399
	Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents)	Oil Spill Contingency Plans - 2000 - 5000 GBP/well (Damage valuation data uses historical data during which time OSCP has been undertaken).	120000	14498.37323	Oil Spill Contingency Plans - 2000 - 5000 GBP/well	120000	1439.029629
		Offshore in-stu burning - 15-39/ of oil burned. (Expected spills totalling 70 te are assumed based upon historical oil spill data). Burning can get rid of 90% of an oil spill. There is a risk of explosion to the facility and/or vessel causing the spill. Total oil burned: 63 te. Total Damage to the Environment from Carbon dioxide (other Atmospheric Emissions are not calculated): 1470.7 - 43,545.6; 5% & 95% percentile.	2730	7983.352683	Offshore clean-up using dispersants - 39-77 GBP/bbl of spilt oil recovered. Conventional dispersants are most efficient with large oil spills and require an application of 10m^3/hour to treat 20 m^3 of oil which is a ratio of 1:2. They are not efficient in calm seas. 6-23 for ecological habitat/te chemical mixture discharged to sea (3.1.7). Total Expected Discharge: 35 te. Total damage to the environment: 210 - 805; 5% & 95% percentile	5390	254.8003848

Impact Significance	Environmental Aspect	Mitigation 'Khencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Khencer'	Mitigation 'Bencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Bencer'
	Carbon dioxide	99.9% Efficient Well-test and Flare-Stack System Evergreen Burner - 34,320 (Capex); Flame Front Generator (FFG) 7,260; Flare boom: 66,000 (All GBP) - Total Cost for 3 facilities: 322,740 - Efficient Well-test and Flare-Stack System - Evergreen Burner 450/day (opex) *(As well as fulfilling safety requirements, flare stacks reduce greenhouse gas emissions and are thus considered an environmental technology).* Increase in amount combusted 7706 te. See Particulates for reduced Environmental Damage.	3157740	947266.2919	99.9% Efficient Well-test and Flare-Stack System Evergreen Burner - 34,320 (Capex); Flame Front Generator (FFG) 7,260; Flare boom: 66,000 (All GBP) - Total Cost for 3 facilities: 322,740 - Efficient Well-test and Flare-Stack System - Evergreen Burner 450/day (opex) *(As well as fulfilling safety requirements, flare stacks reduce greenhouse gas emissions and are thus considered an environmental technology).*	3157740	965497.9629
		Diesel Combustion Technology with all process heating requirements fulfilled by fired heaters - 300-500k GBP (capex); unidentified GBP (opex) - (45 MW) Two Diesel Combustion units required for Production Facility - 144,000 te/year (average) from power generation (12 years) - 1.73 million te;). No opex data identified or economic data for the fired heater system.	-	1779275110.8	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with fired heaters for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the fired heater system. 45 MW Electrical Power Demand - 60,000 te gas/year: Total Emissions to air: 2.06 million te. Total Damage to the Environment: 15,032,160 - 444,787,200; 5% & 95% percentile.	74,940	185794741.9
		Other Activities - 5760 te/60 days (Seismic); 9140 te (average per well (24) from power generation) - 127,960te; 980 te (average from well testing and completion) 23,520 te; 385 te/10 days per well fracturing intervention 9,240 te; 225 te/5 days per well wireline intervention - 5,500 te; 10 te/te of installed and commissioned and decommissioned structure (37,000 te of steel) - 370,000 te; 75 te/ km of pipeline (installation and commissioning of 105 km of pipeline) - 7,875 te. Total Emissions - 549,755 te	-	14057752.62	Other Activities - 5760 te/60 days (Seismic); 9140 te (average per well (24) from power generation) - 127,960te; 980 te (average from well testing and completion) 23,520 te; 385 te/10 days per well fracturing intervention 9,240 te; 225 te/5 days per well wireline intervention - 5,500 te; 10 te/te of installed and commissioned and decommissioned structure (37,000 te of steel) - 370,000 te; 75 te/ km of pipeline (installation and commissioning of 105 km of pipeline) - 7,875 te. Total Emissions - 549,755 te	-	64953392.7
	Oxides of nitrogen	Diesel Combustion Technology with all process heating requirements fulfilled by fired heaters - 300-500k GBP (capex); unidentified GBP (opex) - (45 MW) Two Diesel Combustion units required for Production Facility. No opex data identified or economic data for the fired heater system. Total Emissions to air - 19,774.8 te Total Damage to the Environment: 850,316.4 - 62,448,818; 5% & 95% percentile.	-	42698524.46	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with fired heaters for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the fired heater system. Total Emissions to air: 4550 te. Total Damage to the Environment: 195,667 - 14,370,163; 5% & 95% percentile.	-	2740447.79

Impact Significance	Environmental Aspect	Mitigation 'Khencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Khencer'	Mitigation 'Bencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Bencer'
	Sulphur dioxide	Diesel Combustion Technology with all process heating requirements fulfilled by fired heaters - 300-500k GBP (capex); unidentified GBP (opex) - (45 MW) Two Diesel Combustion units required for Production Facility. No opex data identified or economic data for the fired heater system. Total Emissions to air - 2160 te Total Damage to the Environment:12,960 - 5,346,000; 5% & 95% percentile.	-	5559065.814	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with fired heaters for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the fired heater system. Total Emissions to air: 9.2 te. Total Damage to the Environment: 55 - 22,809; 5% & 95% percentile.	-	5098.428253
	Methane	Diesel Combustion Technology with all process heating requirements fulfilled by fired heaters - 300-500k GBP (capex); unidentified GBP (opex) - (45 MW) Two Diesel Combustion units required for Production Facility. No opex data identified or economic data for the fired heater system. Total Emissions to air - 59.4 te Total Damage to the Environment: 31,244.4 - 93,792.6; 5% & 95% percentile.	-	85796.604	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with fired heaters for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the fired heater system.Total Emissions to air: 662.4 te. Total Damage to the Environment: 348,422-1,045,929; 5% & 95% percentile.	-	518695.2647
	Volatile Organic Compounds	Diesel Combustion Technology with all process heating requirements fulfilled by fired heaters - 300-500k GBP (capex); unidentified GBP (opex) - (45 MW) Two Diesel Combustion units required for Production Facility. No opex data identified or economic data for the fired heater system. Total Emissions to air - 648 te Total Damage to the Environment: 170,424 - 511,920; 5% & 95% percentile.	-	156274.954	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with fired heaters for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the fired heater system. Total Emissions to air: 25 te. Total Damage to the Environment: 6817 - 20477; 5% & 95% percentile.	-	10402.58952
	Hydrogen disulphide	-	-		-	-	
	CFCs, CBCs, HCFCs & and other halons	HCFC phase out by 2015. No alternatives identified.	0		HCFC phase out by 2015. No alternatives identified.	0	
	Sound in Water	Timing of activities following risk assessment - 2000 GBP. It is still considered that without active monitoring that there is a 10% chance that a marine mammal will be affected at some level from disturbance to fatal injury or loss of pod (assumed 40 individuals). Total Damage to the Environment: 1-92; 5% & 95% percentile	2000	27.79569541	Timing of activities following risk assessment - 2000 GBP, and visual monitoring (personel cost 450 GBP/day)	29450	80.08522578
					Ramp up to, delay of, or cessation of firing air-gun array in the presence of vulnerable species - 3000 - 5000/ hr (1/2 day delay due to a 10% chance of a sighting within 500m)	3000	

Impact Significance	Environmental Aspect	Mitigation 'Khencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Khencer'	Mitigation 'Bencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Bencer'
	Odour	See Discharge of Solid Materials	-		See Discharge of Solid Materials	-	
					See Persistent Waste to Land &/or to Sea where Landfill - *11/te (active waste) are included in the overall Decommissioning cost which includes disposal of organic material and not that in Discharge of Solid Material below*	22000	
D	***Seabed Disturbance from Ocean Bottom Cable (Seismic)***	N/A	-		N/A	-	
	Discharge of Solid Material	Transportation of 660 te SBM cuttings to another site for re-injection into subsurface formation due to foreseen change in the las in 2001 where a 1% 'oil-on-cutttings' will be implemented - (legislation permitting) 162.5 - 550/te (capex); 29.4/te (opex). Cuttings slurrified into 132 x 5 te bins and transported to a re-injection site 2 days from field. Fuel consumption by vessel: (2 + 4 (loading and transfer weather permitting))*12 te of fuel/day*Number of wells) 2304 te. Slurrification and re-injection: (Number of wells*mass of cuttings*0.25 te of diesel fuel/te of cuttings) 3960 te. Total fuel required: 6264 te. Total Damage to the Environment from Carbon dioxide (other Atmospheric Emissions are not calculated): 146,327 - 4,329,677; 5% & 95% percentile.	382404	2650103.528	See Oil-based Muds - Discharged to Sea and Capped (See Abandonment of Cuttings Piles above)	0	-
	Heavy Metals	An Environmental Baseline Survey carried out prior to the development provides environmental information including background levels of heavy metals - 80,000 GBP and a risk assessment - 2000 GBP	100000	**The benefit of such surveys and studies can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**	An Environmental Baseline Survey carried out prior to the development provides environmental information including background levels of heavy metals - 80,000 GBP and a risk assessment - 2000 GBP	100000	**The benefit of such surveys and studies can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**
					General Environmental Monitoring - 30,000 GBP/year	360000	
					Implemenation of Environmental Management System to ensure that low toxicity Group E chemicals are used, where possible, in compliance with OCNS - 10,000 - 100,000 GBP/year	100000	
	Sewage & other Facility Wastes	Sewage Treatment Facility - 200 GBP/te	188256.2	nq	Sewage Treatment Facility - 200 GBP/te	188256.2	nq
	Carbon monoxide	Diesel Combustion Technology with all process heating requirements fulfilled by fired heaters - 300-500k GBP (capex); unidentified GBP (opex) - (45 MW) Two Diesel Combustion units required for Production Facility. No opex data identified or economic data for the fired heater system. Total Emissions to air - 4482 te Total Damage to the Environment: 354,078 - 1,416,312; 5% & 95% percentile.	-	882192.8414	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with fired heaters for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the fired heater system. Total Emissions to air: 2160 te. Total Damage to the Environment: 170,640 - 682,560; 5% & 95% percentile.	-	682223.3258

Impact Significance	Environmental Aspect	Mitigation 'Khencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Khencer'	Mitigation 'Bencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Bencer'
	Particulates	The combustion efficiency of the Evergreen Burner reduces the formation of particulates and unburnt hydrocarbons to sea from 53 te to 0.53 te. Total Damage to the Environment: 100 - 401; 5% & 95% percentile.	See Carbon dioxide	248.7225989	See Carbon dioxide	-	495.5088954
		Total remaining particulate production: 245.5 te. Total Damage to the Environment: 46,399.5 - 185,598; 5% & 95% percentile.		46015.59858			
	Social Interaction	Seabed Information Service - no economic data identified	-	nq	Seabed Information Service no economic data identified	-	nq
	Blowout from oil spillage	See *Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents) - although not Environmental Technologies, Blow-out Preventers (BOPs) and increasing the downward pressure of drilling fluids serve to minimise kicks and blowouts.*	-		See *Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents) - although not Environmental Technologies, Blow-out Preventers (BOPs) and increasing the downward pressure of drilling fluids serve to minimise kicks and blowouts.*	-	
E	***Escape of waste to surface (injected waste/produced water)***	Fracture Potential Study carried out to identify appropriate location - assumed to be equivalent to the cost of a Risk Assessment	2000	0	N/A	-	
F	***Presence***	*No mitigation required*	-		*No mitigation required*	-	
	Seabed Disturbance	Use of Dynamic Thruster Positioning - no economic data identified	-		Use of Dynamic Thruster Positioning - no economic data identified	-	
	Injection of Waste into Formation	See Escape of waste to surface (injected waste/produced water)	0		N/A	-	
	Injection of Produced Water into Formation	N/A	-		N/A	-	

Impact Significance	Environmental Aspect	Mitigation 'Khencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Khencer'	Mitigation 'Bencer'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Bencer'
	WBM	N/A	-		N/A	-	
	Brines	Diluted and discharged to sea - 0 GBP	0	nq	Diluted and discharged to sea - 0 GBP	0	nq
	Heated Water	Diluted and discharged to sea - 0 GBP	0	nq	Diluted and discharged to sea - 0 GBP	0	nq
	Sound in Air	Horizontal distance and minimum altitude restrictions - 0 GBP	0	nq	Horizontal distance and minimum altitude restrictions - 0 GBP	0	nq
G	***Disturbance***	Environmental Statement - 81100 GBP (The Environmental Baseline Survey provides preliminary information for the statement)	81100	**The benefit of such statements can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**	Environmental Statement - 81100 GBP (The Environmental Baseline Survey provides information toward the statement)	81100	**The benefit of such statements can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**
H	***Introduction of Foreign Species from Ballasting***	No screening of ballast water samples required	0	nq	No screening of ballast water samples required	0	nq
			188540871.4	**215,370,841**		**281006952**	**259901731.9**

Impact Significance	Environmental Aspect	Mitigation 'Wosta'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Wosta'	Mitigation 'Sbaba'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Sbaba'
A	***Oil-based Muds***	Use Water-based Mud - 8.8 million/well; Total Cost 211.2 million. Incremental Cost considered as Mitigation Cost. 1,599 tonnes average discharge/well (Drilling). (Total Chemicals Discharged to Sea over 1,920 days of drilling 7675 te) Total Damage to the Environment: 46,050-176,539; 5% & 95% percentile.	111120000	[illegible]	Total Containment (OCNS Group Z) - 300-400 GBP/te (includes loading waste for transportation to remote re-injection facility).	6192000	0
	Synthetic-based Muds	N/A			N/A		
	Hydrocarbons to Sea	30 Hydrocyclones, split into two units, one for each separator stage - reduce oil in water content down to 15-35 ppm (throughput capacity: 100-2,500 bwpd) - 0.01 GBP/bwpd (Total Oil Discharged to Sea over 12 years 1509 te) Total Damage to the Environment 9,053-6,913,322; 5% & 95% percentile.	3285000	[illegible]	Gravity Downhole Oil/Water Separation Unit (discharge of produced water at surface eliminated); input: <500 ppm oil-in-water to formation - 10,300 - 17,200 GBP/unit; opex: 0.66 GBP bwpd	216964800	0
		Membrane Filtration (Diffusion barrier technology)- reduce oil in water content to <5ppm (throughput 70 bwpd; input oil-in-water >150 ppm) - 0.01-0.04 GBP/bbl of oil produced (Total Oil Discharged to Sea over 12 years 215 te) Total Damage to the Environment: 1,290-985,130; 5% & 95% percentile.	18480000				
		Monitoring Oil in Outfalls of Water - 30,000 GBP/outfall (capex); 900 GBP/year opex/outfall	204000				
		Onshore Waste Oil Recycling - 29 GBP/te	46.4				
	Abandonment of Cuttings' Piles	WBM and cuttings naturally spread and disperse over the seabed.	0	0	Re-injection in remote facility - *(legislation permitting)* 162.5 - 550/te (capex); 29.4/te (opex)	See Discharge of Solids	
B	***Accidental Discharge of Hydrocarbons to Sea from Tanker Accidents***	N/A			N/A		

Impact Significance	*Environmental Aspect*	*Mitigation 'Wosta'*	*Mitigation Cost £(2000) - highest costs used*	*Environmental Damage £(2000) with Mitigation 'Wosta'*	*Mitigation 'Sbaba'*	*Mitigation Cost £(2000) - highest costs used*	*Environmental Damage £(2000) with Mitigation 'Sbaba'*
C	***Persistent Waste to Land &/or to Sea***	628 te of special waste sent to Licenced Waste Disposal Operator - 150-180 GBP/te (& Facility Waste Control System for domestic waste (Incineration) - no data identified)	113040	0	628 te of special waste sent to Licenced Waste Disposal Operator - 150-180 GBP/te (& Facility Waste Control System for domestic waste (Incineration) - no data identified)	113040	0
		Complete Removal of Facilities - 150 million -180 million GBP	180000000	-781707.6	Complete Removal of Facilities - 150 million -180 million GBP	180000000	-819568.636
		Scrap Steel for Recycling - 50 GBP/te	-249205	1259.744372 -84162.04546	Scrap Steel for Recycling - 50 GBP/te	-249205	2006.577519 -106677.8864
	LSA Scale	Disposal in Permanent Low-level Radioactive Waste Facility - 742 GBP/te	319.06	0	Re-injection in remote facility - *(legislation permitting)* 162.5 - 550/te (capex); 29.4/te (opex), NORM slurrified into 1 x 5 te bins and transported to a re-injection site 2 days from field. Fuel consumption by vessel: (2 + 4 (loading and transfer weather permitting))*12 te of fuel/day) 72 te. Slurrification and re-injection: (mass of waste*0.25 te of diesel fuel/te of waste) 0.25 te. Total fuel required: 72.25 te. Total Damage to the Environment from Carbon dioxide (other Atmospheric Emissions are not calculated): 527.4 - 15,606; 5% & 95% percentile.	249	8842.311848
	Chemical Discharges (other than drilling fluids)	Implemenation of Environmental Management System to ensure that low toxicity Group E chemicals are used, where possible, in compliance with OCNS - 10,000 - 100,000 GBP/year	100000	269.7257386	Implemenation of Environmental Management System to ensure that low toxicity Group E chemicals are used, where possible, in compliance with OCNS - 10,000 - 100,000 GBP/year	100000	252.4503086
	Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents)	Oil Spill Contingency Plans - 2000 - 5000 GBP/well	120000	20390.08545	Oil Spill Contingency Plans - 2000 - 5000 GBP/well	120000	662082.6646
		Offshore clean-up using mechanical containment and recovery - 77-116 GBP/bbl of spilt oil recovered. Cost increases with the size of the spill more than with other methods. Efficiency is compromised by sea state and it is not applicable in rough seas states. Oil is recovered and may be reused. There is no addition of chemicals to the sea. Under the appropriate conditions (wind speed <25 knots; wave current <0.7 knots), it will take less than a day's time to clean up the expected spills. Total Expected Fuel Used: 12 te (for round trip). Total damage to the environment: 280 - 8294; 5% & 95% percentile.	8120	5094.470101	Bioremediation - takes time to act and is not suitable if a fast response is required. There is not that much experience in its use because it is difficult to measure and control the marine environment. (No economic data identified).	-	0

Impact Significance	Environmental Aspect	Mitigation 'Wosta'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Wosta'	Mitigation 'Sbaba'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Sbaba'
	Carbon dioxide	99.9% Efficient Well-test and Flare-Stack System Evergreen Burner - 34,320 (Capex); Flame Front Generator (FFG) 7,260; Flare boom: 66,000 (All GBP) - Total Cost for 3 facilities: 322,740 - Efficient Well-test and Flare-Stack System - Evergreen Burner - 450/day (opex) *(As well as fulfilling safety requirements, flare stacks reduce greenhouse gas emissions and are thus considered an environmental technology).*	3157740	870825.7165	99.9% Efficient Well-test and Flare-Stack System Evergreen Burner - 34,320 (Capex); Flame Front Generator (FFG) 7,260; Flare boom: 66,000 (All GBP) - Total Cost for 3 facilities: 322,740 - Efficient Well-test and Flare-Stack System - Evergreen Burner - 450/day (opex) *(As well as fulfilling safety requirements, flare stacks reduce greenhouse gas emissions and are thus considered an environmental technology).*	3157740	1156589.528
		Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. 45 MW Electrical Power Demand - 45,000 te gas/year: Total Emissions to air: 1.54 million te. Total Damage to the Environment 11,274,120 - 333,590,400; 5% & 95% percentile.	74,940	111135518.8	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. 45 MW Electrical Power Demand - 45,000 te gas/year: Total Emissions to air: 1.54 million te. Total Damage to the Environment 11,274,120 - 333,590,400; 5% & 95% percentile.	74940	289280790.2
		Other Activities - 5760 te/60 days (Seismic); 9140 te (average per well (24) from power generation) - 127,960te; 980 te (average from well testing and completion) 23,520 te; 385 te/10 days per well fracturing intervention 9,240 te; 225 te/5 days per well wireline intervention - 5,500 te; 10 te/te of installed and commissioned and decommissioned structure (37,000 te of steel) - 370,000 te; 75 te/ km of pipeline (installation and commissioning of 105 km of pipeline) - 7,875 te. Total Emissions - 549,755 te	-	79941522.45	Other Activities - 5760 te/60 days (Seismic); 9140 te (average per well (24) from power generation) - 127,960te; 980 te (average from well testing and completion) 23,520 te; 385 te/10 days per well fracturing intervention 9,240 te; 225 te/5 days per well wireline intervention - 5,500 te; 10 te/te of installed and commissioned and decommissioned structure (37,000 te of steel) - 370,000 te; 75 te/ km of pipeline (installation and commissioning of 105 km of pipeline) - 7,875 te. Total Emissions - 549,755 te	-	53533552.87
		Carbon dioxide Sequestration Schemes - 20 GBP/te - Forest Creation 1 km^2: 91,150 te CO_2. (10% reduction of 1,422,461 te)	2844920	-20785118.87	Carbon dioxide Trading - 11.22 GBP/te (10% reduction of 1,422,461 te)	1593156	-15595015.87
					Carbon dioxide Sequestration Schemes - 20 GBP/te - - Forest Creation 1 km^2: 91,150 te CO_2. (10% reduction of 1,280,214 te)	2560430	4916811.648
	Oxides of nitrogen	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 3412 te. Total Damage to the Environment: 146,750 - 10,777,622; 5% & 95% percentile.	-	6456958.58	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 3412 te. Total Damage to the Environment: 146,750 - 10,777,622; 5% & 95% percentile.	-	4669194.044

Impact Significance	Environmental Aspect	Mitigation 'Wosta'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Wosta'	Mitigation 'Sbaba'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Sbaba'
	Sulphur dioxide	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 6.9 te. Total Damage to the Environment: 41 - 17,107.4; 5% & 95% percentile.	-	2631.680119	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 6.9 te. Total Damage to the Environment: 41 - 17,107.4; 5% & 95% percentile.	-	12308.92203
					Emissions Trading - 216 GBP/te	89100	823486.1702
	Methane	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 496.8 te. Total Damage to the Environment: 261316 784447.2; 5% & 95% percentile.	-	725752.4193	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 496.8 te. Total Damage to the Environment: 261316 784447; 5% & 95% percentile.	-	412586.1866
	Volatile Organic Compounds	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 19.4 te. Total Damage to the Environment: 5,112 - 15,357; 5% & 95% percentile.	-	10245.49892	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 19.4 te. Total Damage to the Environment: 5,112 - 15,357; 5% & 95% percentile.	-	9800.947741
	Hydrogen disulphide	-	-		-		
	CFCs, CBCs, HCFCs & and other halons	HCFC phase out by 2015. No alternatives identified.	0		HCFC phase out by 2015. No alternatives identified.	0	
	Sound in Water	Timing of activities following risk assessment - 2000 GBP, and acoustic monitoring (personel cost 450 GBP/day: equipment cost unidentified)	29450	0	Timing of activities following risk assessment - 2000 GBP, and acoustic monitoring (personel cost 450 GBP/day: equipment cost unidentified)	29450	0
		Ramp up to, delay of, or cessation of firing air-gun array in the presence of vulnerable species - 3000 - 5000/ hr (1/2 day delay due to a 10% chance of a sighting within 500m)	3000		Ramp up to, delay of, or cessation of firing air-gun array in the presence of vulnerable species - 3000 - 5000/ hr (1/2 day delay due to a 10% chance of a sighting within 500m)	3000	

Impact Significance	Environmental Aspect	Mitigation 'Wosta'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Wosta'	Mitigation 'Sbaba'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Sbaba'
	Odour	See Discharge of Solid Materials	-		See Discharge of Solid Materials	-	
		See Persistent Waste to Land &/or to Sea where Landfill - *11/te (active waste) are included in the overall Decommissioning cost which includes disposal of organic material and not that in Discharge of Solid Material below*	22000		See Persistent Waste to Land &/or to Sea where Landfill - *11/te (active waste) are included in the overall Decommissioning cost which includes disposal of organic material and not that in Discharge of Solid Material below*	22000	
D	***Seabed Disturbance from Ocean Bottom Cable (Seismic)***	N/A	-		N/A	-	
	Discharge of Solid Material	See Oil-based Muds - WBMs used as a Mitigation Measure and Discharged to Sea and Spreaded over Seabed by Trawling (See Abandonment of Cuttings Piles above)	0	-	Transportation of 645 te OBM cuttings to another site for re-injection into subsurface formation - (legislation permitting) 162.5 - 550/te (capex); 29.4/te (opex). Cuttings slurrified into 129 x 5 te bins and transported to a re-injection site 2 days from field. Fuel consumption by vessel: (2 + 4 (loading and transfer weather permitting))*12 te of fuel/day*Number of wells) 2304 te. Slurrification and re injection: (Number of wells*mass of cuttings*0.25 te of diesel fuel/te of cuttings) 3870 te. Total fuel required:6174 te. Total Damage to the Environment from Carbon dioxide (other Atmospheric Emissions are not calculated): 144,224 - 4,267,469; 5% & 95% percentile.	373713	1,831,893
	Heavy Metals	An Environmental Baseline Survey carried out prior to the development provides environmental information including background levels of heavy metals - 80,000 GBP and a risk assessment - 2000 GBP	100000	**The benefit of such surveys and studies can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**	An Environmental Baseline Survey carried out prior to the development provides environmental information including background levels of heavy metals - 80,000 GBP and a risk assessment - 2000 GBP	100000	**The benefit of such surveys and studies can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**
		General Environmental Monitoring - 30,000 GBP/year	360000		General Environmental Monitoring - 30,000 GBP/year	360000	
		Implemenation of Environmental Management System to ensure that low toxicity Group E chemicals are used, where possible, in compliance with OCNS - 10,000 - 100,000 GBP/year	100000		Implemenation of Environmental Management System to ensure that low toxicity Group E chemicals are used, where possible, in compliance with OCNS - 10,000 - 100,000 GBP/year	100000	
	Sewage & other Facility Wastes	Sewage Treatment Facility - 200 GBP/te	188256.2	nq	Sewage Treatment Facility - 200 GBP/te & Sent to Licenced Waste Disposal Operator - 150-180 GBP/te	451814.88	nq
	Carbon monoxide	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 1620 te. Total Damage to the Environment: 127,980 - 511,920; 5% & 95% percentile.	-	318379.584	Dry Low Emission Combustion Technology for two Gas Fueled Turbines with waste heat recovery for process heating requirements - 537,460 GBP/turbine (capex). No opex data identified or economic data for the waste heat recovery system. Total Emissions to air: 1620 te. Total Damage to the Environment: 127,980 - 511,920; 5% & 95% percentile.	-	278935.8248

Impact Significance	Environmental Aspect	Mitigation 'Wosta'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Wosta'	Mitigation 'Sbaba'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Sbaba'
	Particulates	See Carbon dioxide	-	274.3949224	See Carbon dioxide	-	218.4951437
	Social Interaction	Seabed Information Service no economic data identified	-	nq	Seabed Information Service no economic data identified	-	nq
	Blowout from oil spillage	*See Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents) - although not Environmental Technologies, Blow-out Preventers (BOPs) and increasing the downward pressure of drilling fluids serve to minimise kicks and blowouts.*	-		*See Accidental Discharge of Hydrocarbons to Sea (other than from Tanker Accidents) - although not Environmental Technologies, Blow-out Preventers (BOPs) and increasing the downward pressure of drilling fluids serve to minimise kicks and blowouts.*	-	
E	***Escape of waste to surface (injected waste/produced water)***	N/A	-		Fracture Potential Study carried out to identify appropriate location - assumed to be equivalent to the cost of a Risk Assessment	2000	0
F	***Presence***	*No mitigation required*	-		*No mitigation required*	-	
	Seabed Disturbance	Use of Dynamic Thruster Positioning - no economic data identified	-		Use of Dynamic Thruster Positioning - no economic data identified	-	
	Injection of Waste into Formation	N/A	-		See Escape of waste to surface (injected waste/produced water)	0	
	Injection of Produced Water into Formation	N/A	-		Fracture Potential Study(part of produced water re-injection feasability study) - assumed to be equivalent to the cost of a Risk Assessment	2000	0

Impact Significance	Environmental Aspect	Mitigation 'Wosta'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Wosta'	Mitigation 'Sbaba'	Mitigation Cost £(2000) - highest costs used	Environmental Damage £(2000) with Mitigation 'Sbaba'
	WBM	See Discharge of Solid Material & Heavy Metals	-		N/A	-	
	Brines	Diluted and discharged to sea - 0 GBP	0	nq	Assuming a zero discharge policy in the area - 45-101 GBP/te.	48480	nq
	Heated Water	Diluted and discharged to sea - 0 GBP	0	nq	Diluted and discharged to sea - 0 GBP	0	nq
	Sound in Air	Horizontal distance and minimum altitude restrictions - 0 GBP	0	nq	Horizontal distance and minimum altitude restrictions - 0 GBP	0	nq
G	*Disturbance*	Environmental Statement - 81100 GBP (The Environmental Baseline Survey provides information toward the statement)	81100	**The benefit of such statements can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**	Environmental Statement - 81100 GBP (The Environmental Baseline Survey provides information toward the statement)	81100	**The benefit of such statements can be identified following an appraisal of asset environmental performance undertaken for environmental reporting.**
H	*Introduction of Foreign Species from Ballasting*	No screening of ballast water samples required	0	nq	No screening of ballast water samples required	0	nq
			320142727	128548485.5		412289808	351,377,746

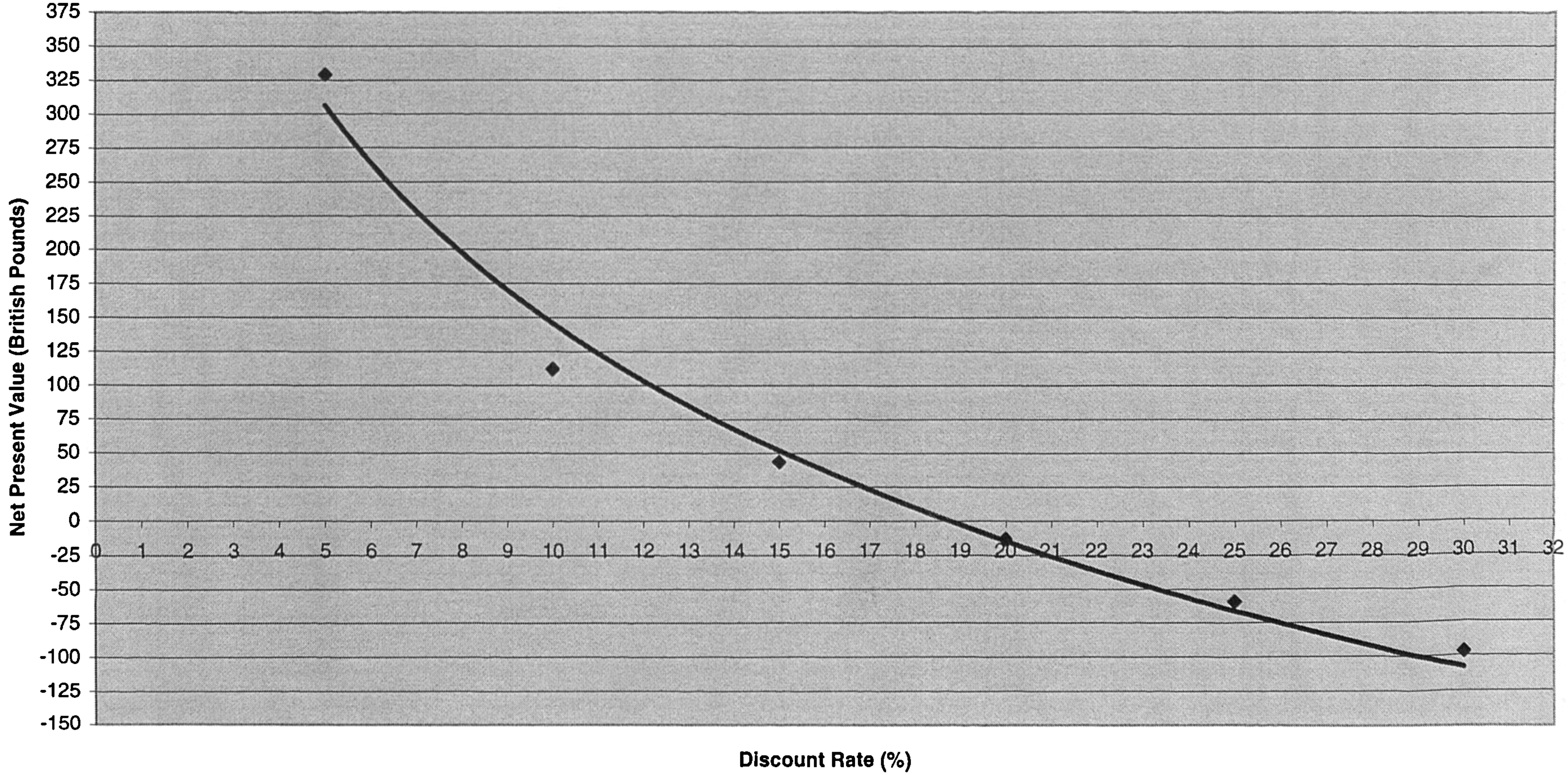
6.4.2 Assessment of the impact of the environmental risk mitigation cost on the project's economic performance indicators such as: net present value and internal rate of return

Field X Cash Flow Model (including Environmental Costs)

Year	Gross	Operating Costs		Rev-Opex	Capital	Env.	N.C.F.	Capital	Capital	Taxable	Tax	N.C.F.	Cum Cash	NPV
	Revenue	Fixed	Variable		Invest.	Mtgtn.	Pre tax	Pool	Allowance	Revenue		Post Tax	Flow	@ 12%
	£ m [mod]	£ m [mod]	£ m [mod]		£ m [mod]	£ m [mod]	£ m [mod]	£ m [mod]	£ m [mod]	£ m [mod]	£ m [mod]	£ m [mod]	£ m [mod]	£ m [2000]
1999	0.00	0.00	0.00	0.00	47.00	0.72	-47.72	0.00		0.00	0.00	-47.72	-50.88	-54.80
2000	0.00	0.00	0.00	0.00	164.40	0.75	-165.15	212.87		0.00	0.00	-165.15	-216.03	-168.44
2001	0.00	0.00	0.00	0.00	171.36	0.78	-172.14	385.01		0.00	0.00	-172.14	-388.17	-147.79
2002	261.15	34.53	4.48	222.14	101.19	0.81	120.14	487.01	121.75	100.39	0.00	120.14	-268.03	88.55
2003	237.95	35.57	1.46	200.92	0.00	0.84	200.08	366.10	91.53	109.39	33.13	166.95	-101.08	105.64
2004	276.79	36.63	-1.04	241.20	0.00	0.88	240.32	275.45	68.86	172.34	36.10	204.22	103.14	110.94
2005	247.57	68.66	-2.51	181.42	0.00	0.91	180.51	207.50	51.88	129.54	56.87	123.64	226.78	57.66
2006	205.95	38.74	-3.07	170.28	0.00	0.95	169.33	156.58	39.14	131.14	42.75	126.58	353.36	50.68
2007	188.91	39.90	-1.14	150.15	0.00	0.99	149.16	118.42	29.60	120.55	43.27	105.89	459.25	36.40
2008	136.09	79.16	4.97	51.96	0.00	1.03	50.93	89.84	22.46	29.50	39.78	11.15	470.40	2.83
2009	123.98	43.60	4.84	75.54	0.00	1.07	74.47	68.45	17.11	58.43	9.73	64.74	535.14	14.08
2010	112.98	58.03	4.71	50.24	0.00	1.11	49.13	52.45	13.11	37.13	19.28	29.85	564.98	5.57
2011	102.88	46.26	4.41	52.21	0.00	1.15	51.06	40.49	10.12	0.00	12.25	38.80	603.79	6.22
2012	93.79	86.97	4.08	2.74	0.00	1.20	1.54	31.57	2.74	0.00	0.00	1.54	605.33	0.21
2013	85.47	49.08	4.05	32.34	0.00	1.25	31.09	30.08	7.52	0.00	0.00	31.09	636.42	3.67
2014	0.00	0.00	0.00	0.00	0.00	313.00	-313.00	335.56	0.00	0.00	0.00	-313.00	323.42	-31.75
Total	**2061.94**	**658.23**	**28.37**	**1431.14**	**483.95**	**327.44**	**619.75**	**-**	**475.83**	**888.40**	**293.17**	**326.58**		**79.69**

Profit to Investment Ratio	**0.83**
Internal Rate of Return %	**18.37**

NPV Profile for Field X (including Environmental Costs)

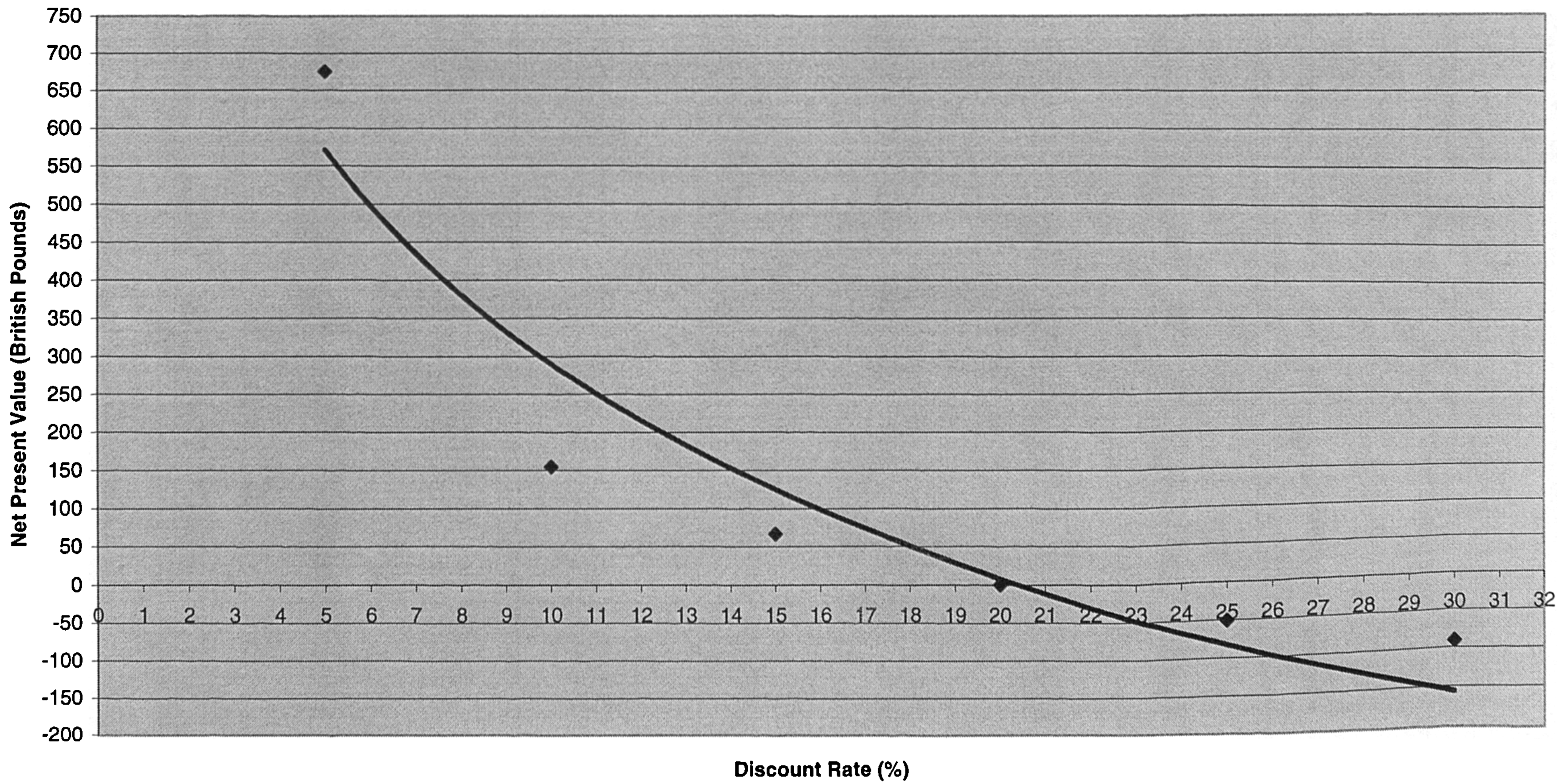


Field X Cash Flow Model (No Environmental Costs)

Year	Gross	Operating Costs		Rev-Opex	Capital	N.C.F.	Capital	Capital	Taxable	Tax	N.C.F.	Cum Cash	NPV
	Revenue	Fixed	Variable		Invest.	Pre tax	Pool	Allowance	Revenue		Post Tax	Flow	@ 12%
	£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[mod]}$		£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[mod]}$	£ m $_{[2000]}$
1999	0.00	0.00	0.00	0.00	47.00	-47.00	0.00		0.00	0.00	-47.00	-50.88	-54.80
2000	0.00	0.00	0.00	0.00	164.40	-164.40	211.40		0.00	0.00	-164.40	-215.28	-168.44
2001	0.00	0.00	0.00	0.00	171.36	-171.36	382.76		0.00	0.00	-171.36	-386.64	-147.12
2002	261.15	34.53	4.48	222.14	101.19	120.95	483.95	120.99	101.15	0.00	120.95	-265.69	89.15
2003	237.95	35.57	1.46	200.92	0.00	200.92	362.96	90.74	110.18	33.38	167.54	-98.15	106.01
2004	276.79	36.63	-1.04	241.20	0.00	241.20	272.22	68.06	173.14	36.36	204.84	106.69	111.28
2005	247.57	68.66	-2.51	181.42	0.00	181.42	204.17	51.04	130.38	57.14	124.28	230.97	57.96
2006	205.95	38.74	-3.07	170.28	0.00	170.28	153.12	38.28	132.00	43.02	127.26	358.23	50.95
2007	188.91	39.90	-1.14	150.15	0.00	150.15	114.84	28.71	121.44	43.56	106.59	464.82	36.64
2008	136.09	79.16	4.97	51.96	0.00	51.96	86.13	21.53	30.43	40.07	11.89	476.70	3.01
2009	123.98	43.60	4.84	75.54	0.00	75.54	64.60	16.15	59.39	10.04	65.50	542.20	14.25
2010	112.98	58.03	4.71	50.24	0.00	50.24	48.45	12.11	38.13	19.60	30.64	572.84	5.72
2011	102.88	46.26	4.41	52.21	0.00	52.21	36.34	9.08	43.13	12.58	39.63	612.47	6.35
2012	93.79	86.97	4.08	2.74	0.00	2.74	27.25	2.74	2.74	14.23	-11.49	600.98	-1.58
2013	85.47	49.08	4.05	32.34	0.00	32.34	24.51	6.13	26.21	0.90	31.44	632.41	3.71
2014	0.00	0.00	0.00	0.00	0.00	0.00	18.38	4.60	0.00	8.65	-8.65	623.77	-0.88
Total	**2061.94**	**658.23**	**28.37**	**1431.14**	**483.95**	**947.19**	**-**	**470.16**	**968.31**	**319.54**	**627.65**		**112.24**

Profit to Investment Ratio	**1.61**
Internal Rate of Return %	**20.03**

NPV Profile for Field X (No Environmental Costs)



7 Discussion

This chapter discusses the Holistic Environmental Assessment (HEA) process and the results of applying it to a real case study Field Development Programme – Field X. It identifies the key findings and uses this case study to identify the strengths and weaknesses of this process. It also discusses the research undertaken to identify the scope of information required for, and the need for, a new technique to assess total environmental risk. It was following an understanding of the interconnectedness of environmental science, social science, law, economics and engineering in offshore oil and gas field development that a process of HEA could be developed.

7.1 LIFE CYCLE ENVIRONMENTAL RISK MITIGATION ANALYSIS (LCERMA)

The Life Cycle Environmental Risk Mitigation Analysis (LCERMA) identifies that the offshore *Field X* development produces a wide range of environmental aspects that transgress atmospheric, marine and terrestrial environments. The analysis further identifies an assortment of techniques to reduce the risk that these pose. These techniques are either; technology to directly reduce interaction with the environment; or, changes in design or the configuration of a field development; or, management-based actions. One of the primary aims of HEA is to facilitate the design of a field development that is both cost-effective and eco-efficient. The LCERMA provides the basic knowledge to achieve this by: breaking down the life cycle of operations; identifying the environmental aspects of each activity in that life cycle; the environmental laws that must be complied with; and the techniques that are available to minimise environmental risk posed by environmental aspects.

7.1.1 Controlling Risks to the Marine Environment

There are a wide range of risks to the marine environment from offshore oil and gas field exploration and development. Environmental risks include: declining seawater quality from hazardous discharges increasing the vulnerability of marine wildlife to disease and changing the biodiversity of marine habitats; bioaccumulation of wastes, particularly persistent organic compounds and heavy metals, in commercial and non-commercial species of fish and shellfish; toxic and physical smothering effects caused from releases of oil; disturbance from sound and general activity changing the population dynamics of whales and dolphins; and the release of persistent waste killing marine animals.

The widest range of available techniques to directly drive down environmental risk was associated with the marine environment. These were techniques designed to limit the quantities and toxicities of oil and chemical discharges, the amount of waste entering the sea, and measures to reduce the impact of sound in water. They included techniques to:

- control and reduce the quantity of oil-in-water: *separators; hydrocyclones; centrifuges; membrane filters; drilling fluid technology; total-containment technology (which includes disposing of oil- or synthetic-based mud contaminated cuttings onshore);*

- reduce the impact of accidentally spilt oil on the environment*: oil spill booms, dispersants, skimmers, sorbents, pumps and specialised vessels; offshore oil spill contingency plans; efficient flare stack systems;*

- control and reduce the impact of chemicals*; SCOPEC chemical usage and discharge monitoring system; Offshore Chemical Notification System (OCNS) updated to implement legal chemical use requirements enforced by the DTI in accordance to the OSPAR Convention; drilling fluid technology; phasing out of the use of synthetic based muds.*

- control and reduce the impact of wastes: *disposal of oil-contaminated wastes on shore; complete removal of oil and gas platforms; seabed clearance and monitoring.*

- identify marine mammals and commercial fish at risk from the seismic activity: *the use of professionals to identify animals at risk by observation; the use of slow ramp-up starts to commence shooting seismic; the use of specific times of the year for shooting at various locations to pose acceptable risk to marine wildlife, these are recommended by nature conservation and commercial fisheries organisations (seismic windows).*

Seismic surveys are conducted to acquire data on the underlying seabed substrata to identify sources of oil and gas. It involves the pulsing of high intensity acoustic signals, using airguns, through the ocean and sedimentary strata. The impacts of these signals on marine wildlife are uncertain. Consequently, the industry acts in accordance to the precautionary principle to minimise the impact of seismic. The principle is only as effective as the number of whales and dolphins sighted, which slight sea state, and lack of light can hinder. Marine mammals are therefore still at risk from seismic until better techniques are employed offshore to identify their location.

The complete removal of platforms is required for all new platforms and results in onshore dismantling, recycling, reuse and disposal. While it is essential that the offshore environment does not become a dumping ground, disposal options that have been suggested by environmental professionals in the past should not be ignored. For example structures sensibly disposed of at sea can provide a substrate for many species of invertebrates and their presence will also act as fish aggregating devices. If in shallow enough water they will offer the same type of enjoyment offered to divers by shipwrecks. Their use could however be put to a more serious purpose. The Southeast of Britain is at risk from the forecasted rise in sea level and such structures could be used in the construction of coastal defences to dissipate wave power.

7.1.2 Controlling Risks to the Atmosphere

There are a wide range of risks to the atmospheric environment from offshore oil and gas field exploration and development. The connection of these risks with the marine and terrestrial environments is far more noticeable. They include: climate change resulting in increases in sea level change, more intense and frequent storms, floods and droughts, cases of malaria, and changes in the biota and food productivity; stratospheric ozone depletion causing increases in skin cancer frequency and severity; and tropospheric ozone formation causing respiratory and cardiovascular disorders and deaths; declining crop yields; and damages in concrete structures.

Atmospheric emissions from UK offshore oil and gas have recently been quantified by the UK Offshore Operators Association's Environmental Emissions Monitoring System (EEMS) and the offshore oil and gas industry has been estimated to contribute between 2%-5% to UK CO_2 emissions. Chapter 2 identifies that the greatest source of global warming gases (GWG) from UK field developments is from power generation. Gas turbine technology is used more often offshore to generate power than diesel driven turbine technology. This is because it is available on many fields at a lower cost to diesel, and is more efficient at converting chemical energy into mechanical energy. The LCERMA identifies that the best available techniques focus on reducing GWG emissions at source by improving the efficiency of power generation.

Other techniques to reduce the impact of GWG focus on reducing the concentration of carbon dioxide in the air and are under research and development. They include: fertilising oceanic phytoplankton; sequestering the gas using algae and bacteria; afforestation; aquifer disposal; injecting the gas into depleted oil and gas reservoirs; sequestering the gas as gas hydrates; using the gas for enhanced coal-bed methane; and emissions trading. Research for this thesis discovered that BP has been running and testing its own internal company inter-field carbon dioxide emission trading scheme. Chapter 3 identified that the current '*best guess*' on the time, which it will take for the implementation of an international trading scheme, is five years away. It appears that in the future there will be techniques: to actively dispose of produced CO_2; to extract CO_2 from the atmosphere for disposal or sequestration; or to use economic instruments to reduce CO_2 emissions by developing new alternative or highly efficient techniques to produce, provide, and use energy. Some of these novel techniques are techniques that are not associated with the production of oil and gas. They can be employed in a location other than that where oil and gas production occurs and still reduce the total environmental risk of the development. This may encourage the use of the Clean

Development Mechanism (CDM), as operators invest in external projects to reduce CO_2 wherever it is most economical to do so. The CDM is detailed under Article 12 of the Kyoto Protocol, and is designed to encourage project activities in developing countries that result in GWG emissions reductions.

Other techniques to control emissions to air included using:

- exhaust gas cleaning systems to control and reduce sulphur dioxide and nitrogen dioxide emissions;
- vapour emission control systems to control and reduce emissions of evaporative volatile organic compounds;
- efficient burner systems to control and reduce GWG emissions from safety purges of natural gas and well testing.

7.1.3 Controlling Risks to the Onshore Environment

Operators compile a waste management plan prepared in accordance to the *Duty-of-Care* regulations to ensure that the handling of waste is lawful and safe. The analysis of onshore waste disposal techniques other than those concerning the treatment of hydrocarbon contaminated cuttings or the fate of decommissioned facilities were considered the responsibility of waste disposal companies and outwith the scope of this study.

7.1.4 Controlling Risks to Land, Sea and Air

Not all environmental risk mitigation techniques were focused on a particular environmental aspect. The preparation of an Environmental Statement, the implementation of an Environmental Management System, workforce environmental awareness training, or the undertaking of an environmental baseline survey are examples of best available techniques that reduce the potential environmental impact of a variety of environmental aspects.

7.1.5 Environmental Law

The offshore oil and gas environmental regulatory regime is becoming wider and tougher in its implementation. Controls have been put in place that have radically changed field development planning. The changing environmental regulations are not just confined to the offshore oil and gas industry. Chapter 4 highlights that from the beginning of 1999, there were over 300 environmental EU Directives and according to officials from the Department of the Environment, Transport and the Regions officials, the number of UK statutes and statutory instruments runs into the thousands.

The Kyoto Protocol focuses attention on global warming gases and energy use. The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000 have been drafted to limit atmospheric emissions from power generation and the DTI have introduced tighter controls on the amount of natural gas that can be flared. The regulations governing chemical discharges are becoming more rigorous with the proposed implementation of a close to 'zero discharge' policy for hazardous substances and a prioritisation mechanism to rank hazardous substances. New decommissioning legislation requires that all new platforms have to be completely removed and disposed of in a safe and environmentally acceptable manner. Any derogation from this can only occur under exceptional circumstances. Table 7.1 details the principal environmental compliance required for offshore oil and gas developments.

Environmental Aspects	*International Legislation*	*Enacted into UK Law by*	*Regulatory Authority*	*Compliance*
PLATFORMS & INSTALATIONS *Physical Presence*				
• of other than temporary installations or pipelines	The 1958 Geneva Convention	CPA 1949	DETR	Consent required
• pipelines only	The 1958 Geneva Convention	PA 1998	DTI	Authorisation required
• Environmental Impact	Amended EA Directive 97/11/EC	OPPP (EA) Regulations 1999	DTI	Consent Required
Discharges of Oil				
• OBM cuttings	PARCOM Decision 92/2	POPA 1971 MSA 1971 and amendments and regulations	DTI & MCA of DETR	Consent required: conditions stipulated by this. There are no controls over the disposal of oil field slurry into substrata offshore.
• Well Testing & Flaring	Annex I MARPOL 73/78 (93 Amended)			
• Production Water	PARCOM Recommendation, Madrid 1986			
• Ballast & Bilge Water	Annex I MARPOL 73/78 (93 Amended)			
• Platform Drainage Water	Annex I MARPOL 73/78 (93 Amended)			
• Oil Spill	Oil Pollution Preparedness and Response Convention	POPA 1971 Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998	DTI	OSCP needs to be authorised by the DTI, & MCA of DETR, and in the case of a spill it is required that the DTI and MCA are contacted immediately
Other Wastes				

• Production discharges	HOCNF	OCNS (voluntary)	DTI	No statutory requirements for consents but a non-statutory scheme requires reporting of certain chemicals and their usage. There are no legal controls over the disposal of produced water into substrata offshore.
• Drilling Discharges	HOCNF	OCNS (voluntary)	DTI	
• Cuttings	London Dumping Convention Oslo Convention	FEPA 1985 The Deposits in the Sea (Exemptions) Order 1985	SERAD/ MAFF	Exemption required
• Garbage	Annex V MARPOL 73/78 (93 Amended)	Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1988	DETR	No consent: conditions stipulated by regulation
• Sewage	Annex IV MARPOL 73/78 (93 Amended)	FEPA 1985 The Deposits in the Sea (Exemptions) Order 1985	SERAD/ MAFF	Exemption
• LSA Scale	No Law Identified	RSA 1993	EA	Authorisation required for accumulation and disposal of radioactive waste
Atmospheric Emissions				
• Flaring & Venting	Kyoto Protocol	Energy Act 1976	DTI	Authorisation to flare of dispose of natural gas
• Power Generation	IPPC Directive 96/61	Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000	DTI	No consent: conditions stipulated by regulation
• Well Testing	Kyoto Protocol	Petroleum Production (Seaward Areas) Regulations 1988	DTI	Consent Required
Disposal at Sea				
• Pipeline commissioning discharges	London Dumping Convention Oslo Convention	FEPA 1985 The Deposits in the Sea (Exemptions) Order 1985	SERAD/ MAFF	Consent Required
• Decommissioning Platforms	OSPAR Decisions 98/3	PA 1998	DTI	Consent Required
• Dumping of other materials and Substances	London Dumping Convention Oslo Convention	FEPA 1985 The Deposits in the Sea (Exemptions) Order 1985	SERAD/ MAFF	Exemption required
SHIPPING				
• Ballast & Bilge Water	Annex I MARPOL 73/78 (93 Amended) & IMO Resolution A.774(18)	PoOP Regulations	DETR	No consent: conditions stipulated by regulation
• Chemical Discharges	Annex II MARPOL 73/78 (93 Amended)	The Merchant Shipping (Dangerous or Noxious Liquid Substances in Bulk) (Amendment) Regulations 1998	DETR	
• Machine Space Discharges	Annex I MARPOL 73/78 (93 Amended)	PoOP Regulations	DETR	
• Atmospheric Emissions	Annex VI MARPOL 73/78 (93 Amended)	No Law Identified	No Law Identified	
• Garbage	Annex V MARPOL 73/78 (93 Amended)	Merchant Shipping (Prevention of Pollution by Garbage) Regulations 1988	DETR	
• Sewage	Annex IV MARPOL 73/78 (93 Amended)	Not yet in force	-	-
• Noise	Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas	Guidelines for the Minimisation of Acoustic Disturbance to Small Cetaceans (voluntary)	DTI	Consent Required
• Oil Spill	Oil Pollution Preparedness and Response Convention	POPA 1971 Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998	DETR	OSCP needs to be authorised by the MCA of DETR, and in the case of a spill it is required that the MCA are contacted immediately

Table 7.1. UK Environmental Law Summary for Offshore Oil and Gas Field Development

It is not just new laws that are being implemented into the UK legal system but also new concepts. In 1999, a judgement by the London High Court was made using the *'precautionary principle'* for the first time in marine environmental case law. The case decided that the challenge by Greenpeace to the Secretary of State of Trade and Industry for failing to apply the Habitats Directive into the 19^{th} Oil and Gas Licensing Round was correct and that the UK Government had made a fundamental legal error.

European Union Directives produced by the European Commission have to be implemented into UK national law by a specified date in the Directive's text. Member State failure to implement a Directive will result in the Government of that State being taken to the European Court of Justice, and if found to be in breach of the Directive will be fined. The EU is not the only organisation creating new laws that need to be kept track of. The UK is also a signatory to the OSPAR Convention and implements Decisions made by the Oslo and Paris Commission under the convention into national law. The most recent Decision being OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations. The development of an oil and/or gas field is a long-term business and retrofitting technology to comply with new environmental regulations is costly. Environmental standards will be tougher in ten years from now. Thus it is not surprising that the industry aims for higher environmental standards to those stipulated by law to keep ahead of changing and uncertain environmental regulations and avoid these potential future costs.

7.1.6 Environmental Risk Mitigation Costs

In this thesis environmental risk mitigation costs are obtained from a wide range of sources. These were principally scientific and engineering journals and are detailed in section 3.3.1.1. The economic data presented in journal studies was stated as either operating expenditure (opex) or capital expenditure (capex), or both. In certain cases it was not clear whether it was opex or capex. Costs were also obtained by consulting with operators and relevant stakeholders such as oil service companies and environmental consultancies, and by, sending questionnaires. Economic data could not be collected for all the environmental risk mitigation techniques and for some it was incomplete. The majority of operators, in reply to questionnaires, stated that they did not have the manpower resources to gather the numerous types of economic information. As a result of the above there is uncertainty over the cost of environmental risk mitigation in the application of HEA to Field X.

7.2 TOTAL ENVIRONMENTAL RISK ASSESSMENT (TERA)

7.2.1 The Carrying Capacity of the Environment

The Total Environmental Risk Assessment (TERA) identifies that there are serious immediate risks to the environment that are affecting its carrying capacity, and are also growing in severity. Ignoring these risks by a continual production of a wide range of environmental aspects will have deleterious effects. Especially if no effort is made to combat the environmental risk posed by them. The atmospheric and marine environmental aspects from upstream oil and gas field development contribute, or have the potential to contribute to, serious changes to the environment. Three of these risks are serious enough to warrant international action and include climate change, stratospheric ozone depletion and oil pollution. The other risks affect the Northeast Atlantic region and are being tackled primarily by European Union regulatory measures. They include:

- Tropospheric ozone
- Marine environmental degradation
- Commercial fish stock levels
- Acidification
- Degradation of coastal sights
- Eutrophication
- Groundwater degradation
- Species loss
- Inefficient resource use.

International action to combat environmental degradation is achieved by preparing and ratifying legally binding treaties and conventions. Treaties and conventions appear to be failing where: degradation occurs far from its source; the lack of infrastructure increases the cost of mitigation; and, the enforcement of controls to mitigate environmental risks are in conflict with other industries or the peoples' lifestyles.

7.2.2 Environmental Impact Pathways

The development of environmental impact pathways allows the potential environmental impacts associated with environmental aspects to be identified. When completed it was discovered that the impacts were generic i.e. the information collected could be used for any oil and gas field development in the Northeast Atlantic. In addition the majority of the pathways could be used for other offshore industries. There are however, a minority of industry specific environmental aspects such as drilling fluids that require a specialised impact pathway analysis due to their unique chemistry. There is a further form of commonality. The link between environmental impacts, environmental aspects and the best available techniques to reduce environmental risk is common to all types of field developments.

7.2.3 Impact Pathway Modelling & Risk Assessment

Models are useful tools to predict environmental impact. The models used offshore focus mainly on marine environmental impact. There were few discovered that modelled emissions to air. Marine-based models are increasingly using data from historical environmental impact studies, undertaken offshore, to improve their predictive ability. A comprehensive HEA involves modelling environmental aspects. The modelling of environmental aspects was however not undertaken in the analysis of Field X. The environmental burden of Field X was calculated from data present in the Development Programme for Field X, industry-specific historical data collected together from environmental appraisal studies and Environmental Statements. Thus the data used to calculate environmental burden was a mix of both engineering and environmental data. Since it was not from one source there is a level of uncertainty associated with it. Fugitive emissions were not quantified in the HEA of Field X due to a lack of appropriate data. Many of the referenced studies had used the models detailed in Appendix 1 to assess environmental impact. There are two chief limitations associated with using models to assess potential environmental impact:

- Some impacts are unable to be modelled due to the complexity and diversity of ecosystems and the interactions of species within those ecosystems. Environmental impact may shift the equilibrium of environmental quality to a different level, which may be opportunistic for some species or populations within that species, and disastrous for others, the interactions of which are difficult to model.

- The certainty to which an impact is modelled decreases further down the environmental impact pathway. Environmental impacts that are cumulative and/or synergistic (since they involve pollutants from other sources) are difficult to model with certainty.

Historical data and trends combined with models will reduce uncertainty and offer the greatest predictive ability. Balance has to be struck, by expert judgement, between how much modelling analysis and data gathering is required to assess whether an impact will adversely damage the environment. The information that is provided by this phase is specific to the field development. This information, when combined with the qualitative information obtained in the previous phases, provides an engineer with an environmental information system, which is used to calculate the level of environmental risk that each environmental aspect will pose.

7.2.4 Risk Assessment

The risk assessment is the phase of HEA that prioritises environmental aspects. HEA evaluates data from a variety of disciplines and therefore requires a level of subjective judgement. A screening process detailed in section 5.4.3.6. is used to facilitate decision making and make any judgement as objective as possible. The screening process is designed to highlight significant risks by evaluating: the frequency of the aspect; impacts to the living, non-living environment and other users of the sea; legal infringements; impacts to the operating company; and, public concern. The environmental aspects are then prioritised using risk index that is linked to the As-Low-As-Reasonably-Practicable principle. Under this paradigm, a significant environmental aspect is one that is not acceptable to society without action to mitigate against its adverse impact. The prioritised list of risk-assessed environmental aspects for Field X is detailed in Chapter 6. The intolerable environmental aspects (i.e. where the environmental risk cannot be justified on any grounds) were: *OBMs to Sea; SBMs to Sea; Hydrocarbons to Sea; Leaving Exploration and Production Infrastructure Offshore; Abandonment of Hydrocarbon Contaminated Cuttings Piles; Accidental Discharge of Hydrocarbons from Tankers.* UK law strictly controls these environmental aspects and to ignore the findings of the screening process would risk breaking the law.

The identification of what environmental aspects will generate public protest is a difficult and subjective area. The Brent SPAR incident highlights that the media is linked to public protest. Media headlines tend to reflect society's fears that an environmental risk will damage livelihoods, eliminate 'cared for' species, degrade vast areas of wilderness, or affect human life itself. Such concerns were identified in the Environmental Impact Pathway Analysis by reviewing environmental news items.

The Brent SPAR protests were also linked to another, more subtle factor. Section 4.5.6.1. identified that this factor is the *trustworthiness* of an organisation. Environmental Risk Assessors are identifying that a sudden failing of a placed trust by society upon an organisation will result in protest (Pidgeon, 2000). Offshore operators have identified that they need to demonstrate to society that it knows it is corporately responsible and accountable for its environmental performance, and that it is adopting a 'clean production' approach. At the Health, Safety and Environment Management Roundtable of Offshore Europe'97, three keywords from a series of discussions were adopted by UKOOA: Transparency; Expectations; and Training. These concepts evolved as the industry identified that it wasn't where it should be with the society and the environment.

All the environmental aspects that are identified in the risk assessment as being significant require some level of mitigation. The ALARP principle determines the level of mitigation. Those environmental aspects, whose environmental risk is classified as *Intolerable*, (where the risk cannot be justified on any grounds), are mitigated against whatever the cost. Under the *Maximum Tolerable Level*, the level of mitigation is limited by cost and benefit. The risk is tolerated if the cost of mitigation exceeds the environmental benefit disproportionately, or risk reduction is unfeasible due to excessive cost. The remaining significant environmental aspects are classified under the *Maximum Just About Tolerable Level.* The risk posed by the environmental aspect is considered low enough that it will be tolerated if the cost of reduction exceeds the improved gain. The prioritised environmental aspects provide important information around which an engineer can design an environmental risk mitigation system. There are two weaknesses with this process: (1) the ALARP principle is bias towards cost; and, (2) the use of frequency can reduce the risk index of an environmental aspect that is considered intolerable e.g. oil spillage from a blowout.

7.2.5 Valuing Environmental Damage

Before any environmental risk mitigation system is proposed there is a need to identify a benchmark of environmental performance upon which such systems can be compared. The benchmark used in HEA is the amount of total environmental damage that a field development will cause without any mitigation. A monetary value is used to quantify the total environmental damage from a multitude of different environmental aspects. There is no other value that is flexible enough so that this may be achieved.

7.2.5.1 Environmental Damage Cost Factors

The various factors associated with environmental impact, once identified, are used to determine the type of environmental change caused by an environmental aspect. The Field X analysis groups these factors into types of change that could be quantified as environmental damage costs using environmental-economic literature. The key changes that are quantified include:

- Habitat loss and/or creation;
- Species loss and/or introduction of others;
- Human health
- Crop productivity;
- Property values;

- Fishery catch;
- Number of visits to marine and coastal parks;
- Repatriation of refugees.

In a case where an environmental aspect was linked to a change in the environment that produced no quantifiable environmental damage, further analysis was required to identify any subsequent, potential environmental damage that could be quantified. For example, the injection of waste into a reservoir may cause formation damage. Such damage is not currently valued by society. Whereas a fracture propagating to the surface may release hazardous waste into the sea or onto the land causing damage, which is valued.

Social changes were not included in the analysis. Such changes include: the long-term welfare of communities; cultural development; crime levels; the cost of living; and, social work levels. The relationship between the environment and society is complex and would involve further economic analysis, which is outwith, the scope of this thesis.

7.2.5.2 Environmental Damage Costs

Calculating the monetary values for environmental damage is a complex and debatable subject. The values used in this study are from two types of valuation, Contingent Valuation Method and Indirect Valuation Method (detailed in Appendix II). The Contingent Valuation Method (CVM) is a survey-based approach that asks individuals to value environmental quality. Values from these contingent valuation studies assess the amount individuals are willing to pay (WTP) to avoid, or willing to accept (WTA) as compensation for, the environmental damage. The Indirect Valuation Method (IVM) calculates the dose-response or exposure-response relationship between pollution and environmental impact. They value the relationship between the dose (pollution) and the macro-economic effect (low crop productivity or the impact of rising levels of particulates on health services in cities, for example).

It is because contingent valuation uses personal WTPs and WTAs that economists are constantly debating over its use. Some favour it:

"Contingent valuations are, and will continue to be, suitable for Environmental Damage Assessment."

(Portney, 1994)

Others consider that it is a deeply flawed method for measuring externalities and that it should not be used for Environmental Damage Assessment:

"Increasing sample size can usually decrease the uncertainty of data. In contingent valuations the reliability of data is not reduced by sample size. We conclude that current contingent valuation methods should not be used for damage assessments or for benefit cost analysis."

(Diamond & Hausman, 1994)

Holistic Environmental Assessment uses secondary information and its quality is only as valid as the information drawn from the studies it uses. There are the following possible areas of uncertainty associated with using environmental values from other studies:

- Anthropocentric Values: an environmental aspect will only have economic value if it enters at least one individual's utility function or a company's production function. The problem with this is that if there is an element of the natural capital stock (undiscovered genetic material or diseases, a view, an insect or a rocky outcrop at sea with breeding birds) that does not enter an individual's utility function or a company's production function, then it has no monetary value.

- The Ill Informed: economic value is measured by the summation of individual preferences for a particular environmental aspect. This study assumes that individuals are perfectly informed. There is a risk that individuals in the historical studies used were not well informed. For example the preservation of forests halts soil erosion and surface runoff to the sea and inland waterways. This will prevent nitrates and phosphates from causing coastal eutrophication and suspended matter causing operational difficulties for the water treatment industry. Unfortunately fish farmers and engineers may be ignorant of the importance of maintaining certain forested areas when asked to state or reveal their preference for preservation and bid a low value in a contingent valuation. An ecologist is aware of these problems but his/her value vote may be overwhelmed by the combined values of the others.

- Property Rights: environmental valuation studies can act as an economic version of democracy. The environment aspect may be valued less when the individuals in the area want the project to go ahead and are asked how much they are willing to pay for its loss. There may be a minority who are at risk from that environmental aspect and because of the project are willing to accept only a very large amount of compensation for its withdrawal from their livelihoods. These amounts could jeopardise the project and thus the property rights of the many would have transferred to the few.

- Bias: the above example illustrates the potential for bias. This is the apparent discrepancy (variability) between willing to pay and willing to accept values. This is strategic bias. The bias is the result of individuals exaggerating their willingness to accept values and underestimate their willingness to pay values, with the hope that they will receive additional compensation. Economists refer to it as free-riding. A comparison of contingent valuation results with other environmental valuation techniques reveals an accuracy range of +/- 60% (Pearce et al., 1989).

- Reductionism and Ecosystem Complexity: the concept that the value of something is the summation of individual preferences is inconsistent with the ecological concept that the value of the whole is greater than the sum of its parts.

- Irreversibility: environmental aspects may cause an impact on the environment that is irreversible. The loss of a species or freshwater in an area, or sea level rise will ensure that the benefits of preservation are gone forever. The benefits of a project that is causing the impact have a fixed life-span. It is considered that as particular environment resources become scarcer then the value of preservation will grow positively.

- Institutional Capture: it is recognised that individuals responsible for undertaking environmental economic studies can do so in a way that may serve their own interests rather than those of society. Organisations may have vested interests that influence the outcome in their favour and bring it into disrepute. Factors that may cause this design bias include:

- the procedure used to forecast future benefits and costs;
- the screening process used to assess significant impacts; or
- the assumptions made regarding how the environmental economic values are calculated.

It was considered in a London Environmental Economic Centre Report prepared for the Department of the Environment that many indirect valuations have not adequately analysed dose-response relationships. In the case of materials corrosion, much of the literature reviewed was financed by private industry and commercial interest has directed which materials were investigated (Pearce et al., 1989).

- Establishing the Link between Damage and Monetary Value: there are potential difficulties in establishing the relationship between ambient pollution levels and, animal and plant morbidity and mortality. The observations of environmental damage are made in real life settings and there are difficulties in controlling the influence of extraneous variables in such studies.

HEA aims to combat the uncertainty associated with handling environmental damage costs, by using values from a database of different studies, and representing them as a cumulative probability distribution function curves of the environmental damage for each environmental aspect. Crystal Ball software was used to plot the distributions for Field X. The lowest and highest values of damage for an environmental aspect identified from the database are used to represent the 5^{th} percentile and 95^{th} percentile of the distribution because the mean value for environmental damage is unknown. This assumes that these values are within $>1.65\sigma$ and $<2\sigma$ from the mean environmental damage cost. This method is detailed in sections 5.4 & 5.5. It is understood that to claim that HEA would not be affected by any of the above uncertainties would be unrealistic. The use of qualitative and quantitative information from a wide range of sources (a large proportion of which is generic and founded on a history of scientific environmental appraisals) should minimise this risk.

7.2.5.3 Environmental damage costs versus energy-based values

Environmental damage costs are favoured for HEA because the only other alternative is to use energy-based values. There are no other indicators that can be aggregated together to represent the life cycle environmental performance of oil and gas field development. Energy-based values are effective at assessing a process's mass balance of energy use. If a process is losing large amounts of energy to the environment it is considered to produce significant environmental impact. This measure of efficiency however will not differentiate various environmental impacts produced by the activity under analysis. This is because the value of energy efficiency may be the same even though total production has been increased or the method of production has changed. For example an assessment of the efficiency of agricultural practice may identify that the feeding of offal to cattle is an efficient process but it will not identify risks to human health from bovine spongiform encephalopathy/Creutzfeldt-Jacob disease. The use of environmental damage costs in the HEA process is important because they can differentiate between the damage (impact) that different environmental aspects will cause and be used with qualitative information to assess total environmental risk.

7.3 ENVIRONMENTAL RISK MITIGATION SYSTEM ANALYSIS

7.3.1 Monte-Carlo Analysis

Monte Carlo Analysis is used to plot the Environmental Damage Distribution Curves for the 5 field development designs proposed for Field X; Ebham, Khencer, Bencer, Wosta and Sbaba. The method is discussed in section 5.5. Ebham is an illegal proposal because it breaks offshore environmental law, and therefore produces no environmental benefit. It was used as a control and the environmental damage that it produced, as a baseline for comparison to calculate environmental benefit by subtracting the environmental damage of the other designs from it. An environmental benefit to environmental risk mitigation cost ratio was computed and to identify an Environmental Risk Mitigation System (ERMS) for Field X that was both eco-efficient and cost effective.

The level of environmental benefit produced varies for each of the 4 designs. Those environmental aspects that could not be quantified from the database of environmental economic information were prioritised in accordance to their risk-based weightings. This ensures that environmental aspects are not discarded on the basis that they cannot be valued. Table 7.2. details the potential environmental performance of each of the ERMS.

Field Mitigation Design	*Total Mitigation Cost (£m)*	*Environmental Benefit (£m)*	*Benefit/Cost*	*Unquantifiable Environmental Aspects – ALARP prioritisation*
Ebham	0	0	0.00	(illegal operation)
Sbaba	412	100	0.24	1. **Maximum Tolerable Region** • CFCs/HCFCs • Sound in Water • Heavy Metals • Sewage • Fishing Industry 2. **Maximum Just About Tolerable Region** • Brines • Heated Water • Sound in Air 3. **Acceptable Without Action** • Disturbance • Introduction of Foreign Species from Ballasting
Wosta	320	125	0.40	
Bencer	281	-5	-0.02	
Khencer	189	49	0.26	

Table 7.2. Field X Environmental Risk Mitigation Systems

Conventional economic theory states that where benefit *is equal to* cost, the most effective level of investment can be identified. This theory applies to one environmental aspect only and not a range of them. It suggests that the cost of no environmental risk mitigation action increases the likelihood of environmental damage from an environmental aspect occurring, and that inaction would be justified if the costs were greater than the benefits (Begg 1984). Conventional economic theory calculates benefits as savings gained from not having to clean up and restore the environment from damage (had no investment into preventative techniques been undertaken and a serious environmental impact occurred). This theory is not applicable to HEA because the process:

1. assesses the total environmental benefit from a number of different environmental aspects;
2. uses values from studies that aim to estimate what the environment is worth to society, and adds these values to give a total environmental benefit value. These are non-market values. It does not estimate environmental benefit as the savings made on restoration costs.
3. Preventative and restoration costs are market-based values. They are real and if incurred will be included in the operator's annual financial report. The benefits are non-market values. They represent environmental quality and resource scarcity.

For these reasons, optimum environmental expenditure cannot be the point where environmental benefit equals the cost of environment risk mitigation in HEA. HEA uses environmental benefit as a performance indicator (along with the unquantified information) to identify an environmental risk mitigation system for a field development programme that is eco-efficient. The benefit/cost ratio, detailed above, is the indicator that will identify the most eco-efficient and cost effective environmental risk mitigation system, and may greater or less than 1.

Khencer was identified as the design out of the four that steers the operator toward the triple-bottom line of Sustainable Development. It offers environmental benefit at a much reduced environmental cost when compared with *Sbaba* or *Wosta*. *Bencer* on the other hand even after considerable investment did not offer environmental benefit. Investment into certain environmental aspects will reap environmental benefit and others will not. Only when the total environmental damage is estimated for a design and compared to a control so that it can be ascertained whether any environmental benefit is produced. Figures 7.1 – 7.4 detail the environmental performance of the field design proposals: Figure 7.1 demonstrates the level of environmental damage; Figure 7.2 the level of environmental benefit; Figure 7.3 the environmental benefit versus cost; and 7.4 illustrates the relationship between investment into a clean production approach and environmental benefit.

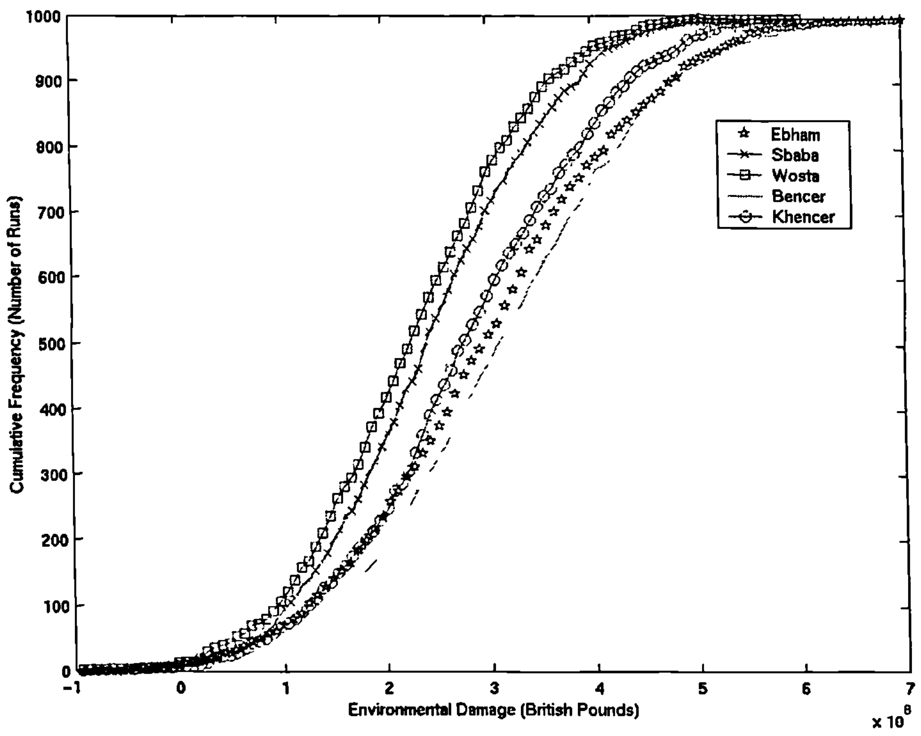


Figure 7.1. The Effect of Field X's Environmental Risk Mitigation System Proposals on the Environment

The Cumulative Distribution Function (CDF) curves of environment damage for the total environmental damage for each of the ERMS are similarly shaped, steep and closely grouped. This is because the total amount of environmental damage of the least and most damaging ERMS does not differ by much more or less than $1*10^8$ (£2000) between the mean and the 95% probability function. This supports the theory that any activity will interact with the environment and in HEA it is this interaction that is valued as environmental damage. Ebham reflects the environmental damage cost associated with the existence of Field X. The ERMSs should reflect a reduction on the environmental damage that Ebham causes. They are all related to the environmental damage produced from the same field facility configuration and are thus similar shapes. If these were different then the shape of total environmental damage CDF curves would change. It can be seen that Bencer is producing, even with the considerable amount of investment into environmental risk mitigation, a similar amount of environmental damage as Ebham. In Figure 7.2. this observation is supported by the fact that Bencer produces no environmental benefit. The negative values in Figure 7.1. reflect the very low probability that the negative environmental damage values of environmental risk mitigation techniques of carbon sequestration, carbon trading, recycling steel and recycling production facilities exceed those that are positive and reflect a negative total environmental damage.

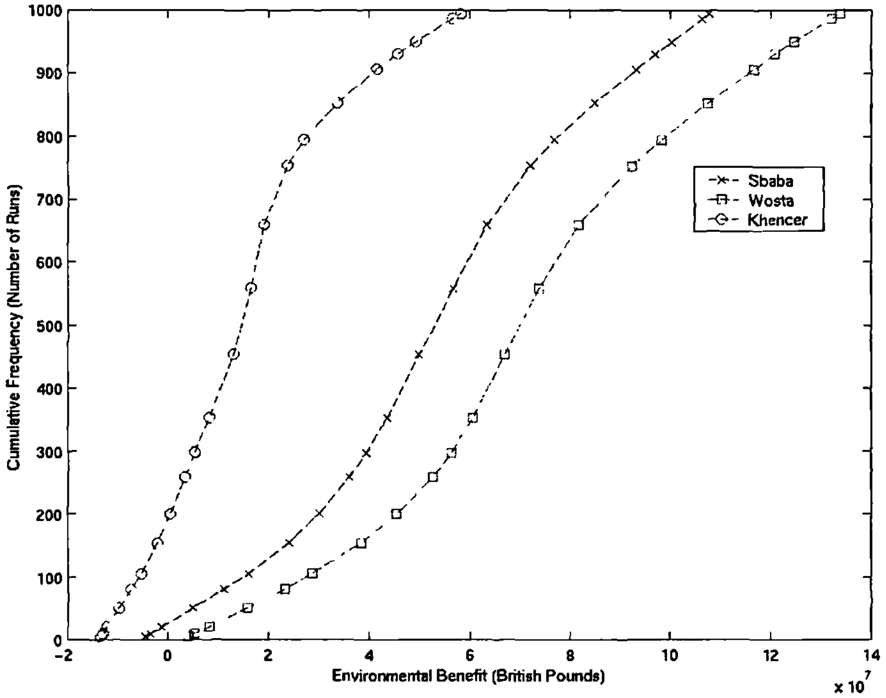


Figure 7.2. The Environmental Benefit of Various Environmental Mitigation Proposals for Field X

The shape and position of the CDFs in Figure 7.2. are different to those in Figure 7.1. One of the ERMSs, Bencer, produces no environmental benefit and is therefore not represented in this Figure. Sbaba and Wosta produce similar CDF curves. Both produce slightly less steep slopes that commence with negligible or no environmental benefit and finish with considerable environmental benefit. Khencer on the other hand produces a steeper sloping curve. This is due to the type and level of environmental risk mitigation. For each of the curves there is a low probability that the environmental damage from the environmental risk mitigation is higher or almost as high as the environmental benefit that it produces. In this application it is the carbon dioxide emissions, which are caused by decommissioning, re-injecting oil-based mud and NORM waste into a remote location, and from other activities, and dispersant use from oil spill clean-up procedures, that causes the environmental benefit to be reduced by increasing amounts of environmental damage. Thus an ERMS with a low level of mitigation activity is likely to have a steeper curve compared to a system with a high level as the relationship between damage and benefit is simplified. The environmental benefit at the 95% probability for each of the

ERMSs detailed in Figure 7.2. is a positive result of investment into 'best available techniques' for this particular field development.

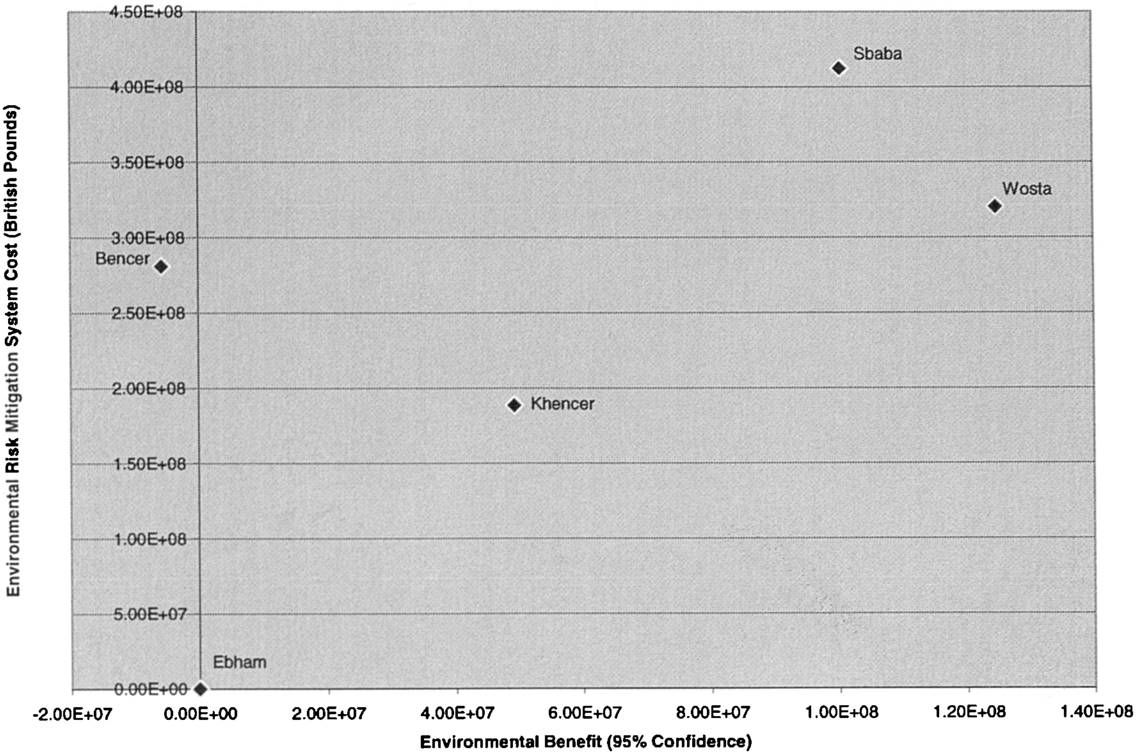


Figure 7.3. Environmental Benefit versus Mitigation Cost for Field X

Figure 7.3. shows that there is no relationship between investment into risk mitigation and environmental benefit for Field X. Figure 7.4. presents the Benefit/Cost ratio of the ERMS proposals. Khencer not only produces a comparatively high level of environmental benefit per £ invested, but also costs less than either of the other two candidate systems, Sbaba and Wosta. Figures 7.3. and 7.4. illustrate that it is essential to choose the right environmental risk mitigation techniques for a field development. For example, there are costly techniques in the Sbaba ERMS, which appear to be implemented to reduce environmental damage in one area only to increase it in another.

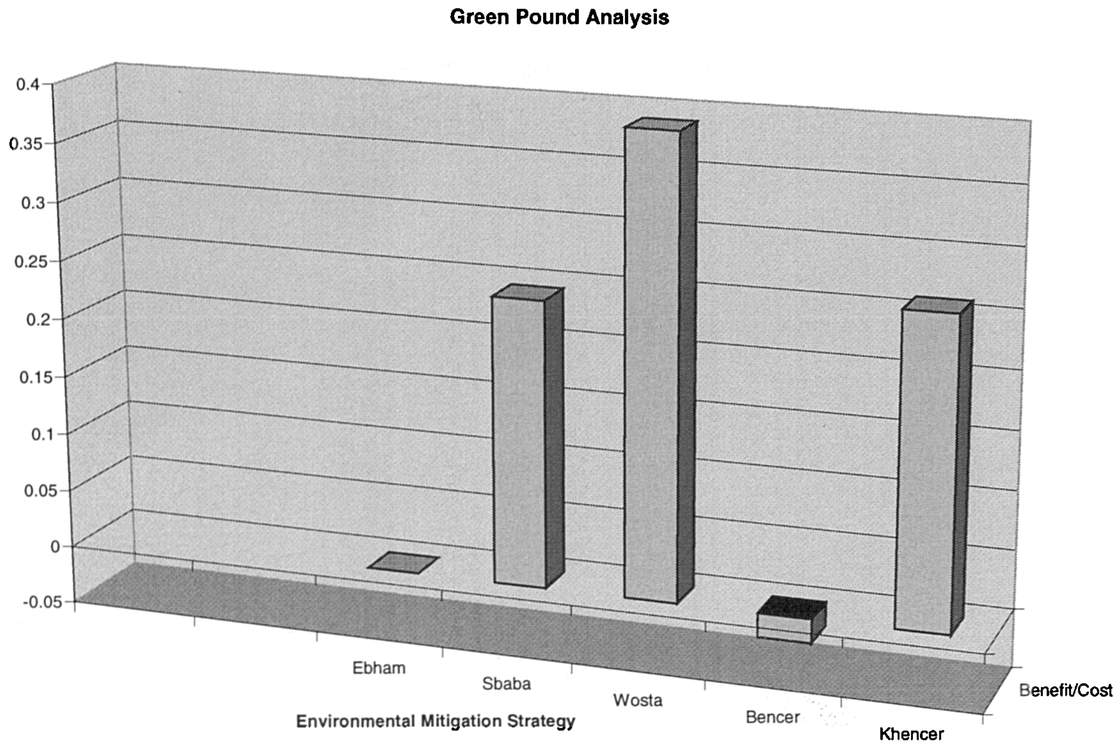


Figure 7.4. Green Pound Analysis for Field X

The proposed systems other than the control are using risk environmental mitigation techniques, which are best available techniques, and yet some factors are when taking a holistic perspective, having a significant effect on the environmental damage and benefit. It is necessary to find out which of these is having the greatest influence to understand the systems' environmental performance.

7.3.2 Sensitivity Analysis

A sensitivity analysis was conducted to discover what factors were having a significant effect on the total environmental damage of the various environmental risk mitigation systems for Field X. This helps to identify where: (1) changes can be made to improve environmental performance; and, (2) techniques have been implemented that transfer environmental risk elsewhere. The sensitivity analyses are detailed figures 7.5-7.9.

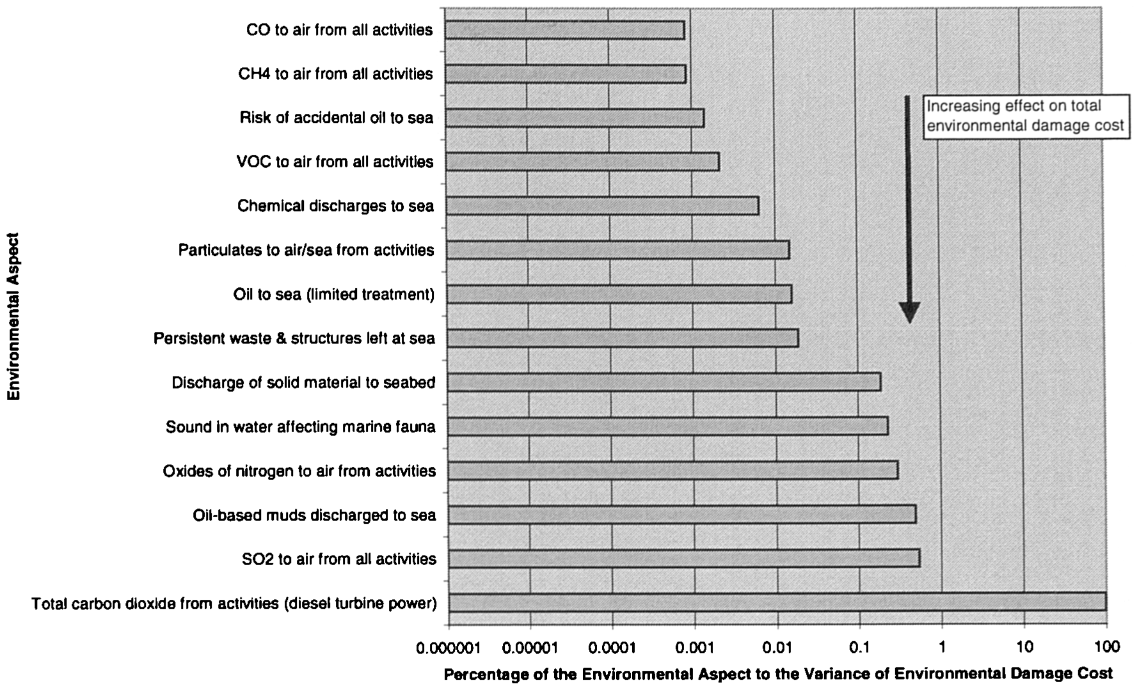


Figure 7.5. Environmental Risk Mitigation Design System *'Ebham'* Sensitivity Analysis (control)

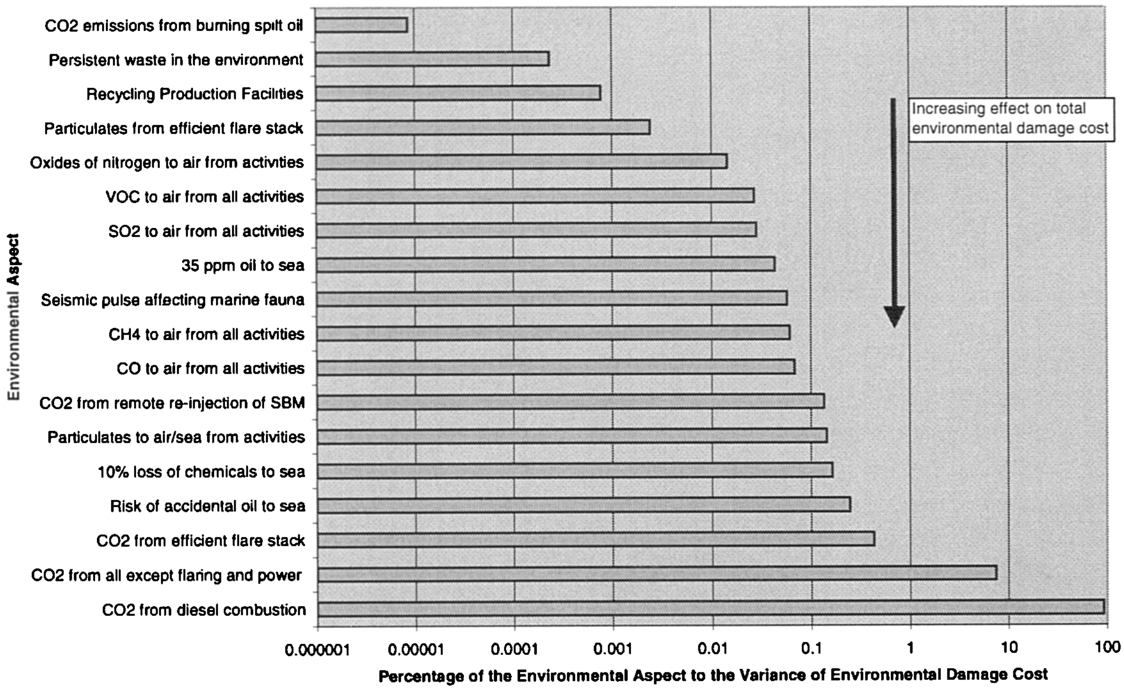


Figure 7.6. Environmental Risk Mitigation Design System *'Khencer'* Sensitivity Analysis

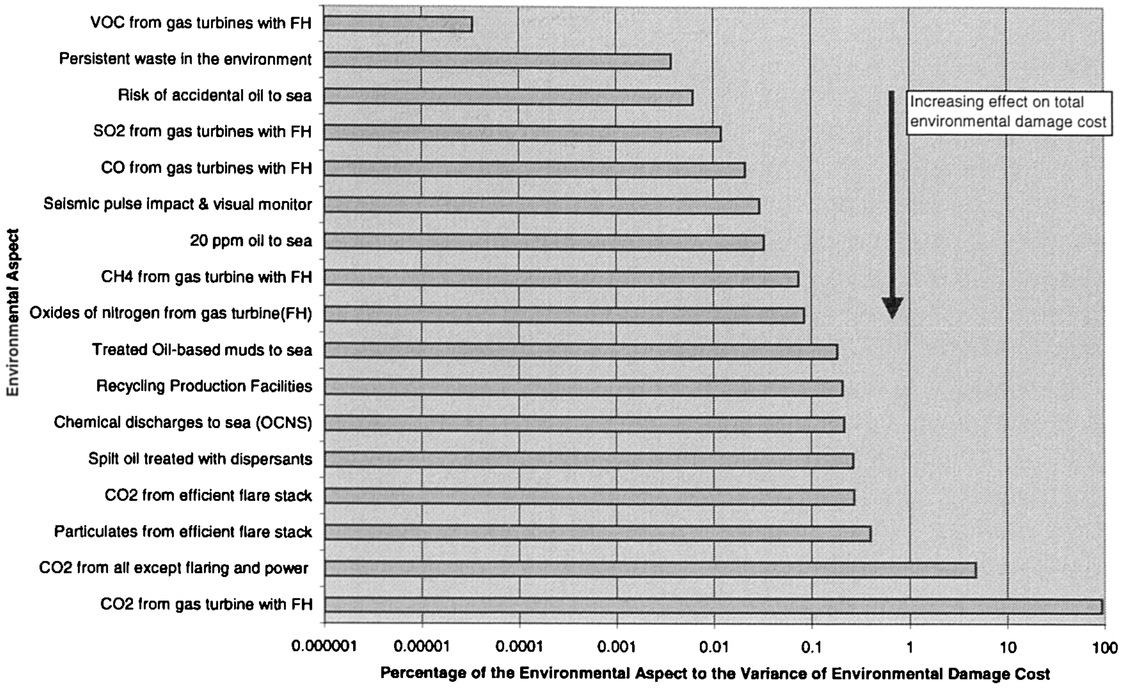


Figure 7.7. Environmental Risk Mitigation Design System *'Bencer'* Sensitivity Analysis

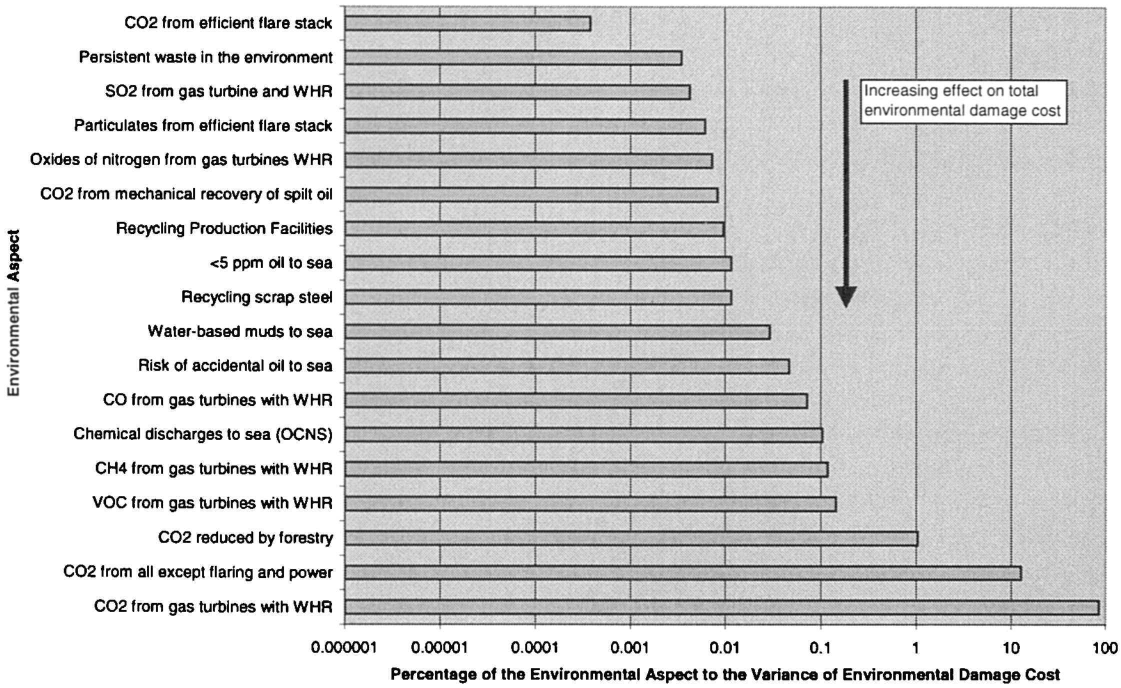


Figure 7.8. Environmental Risk Mitigation Design System *'Wosta'* Sensitivity Analysis

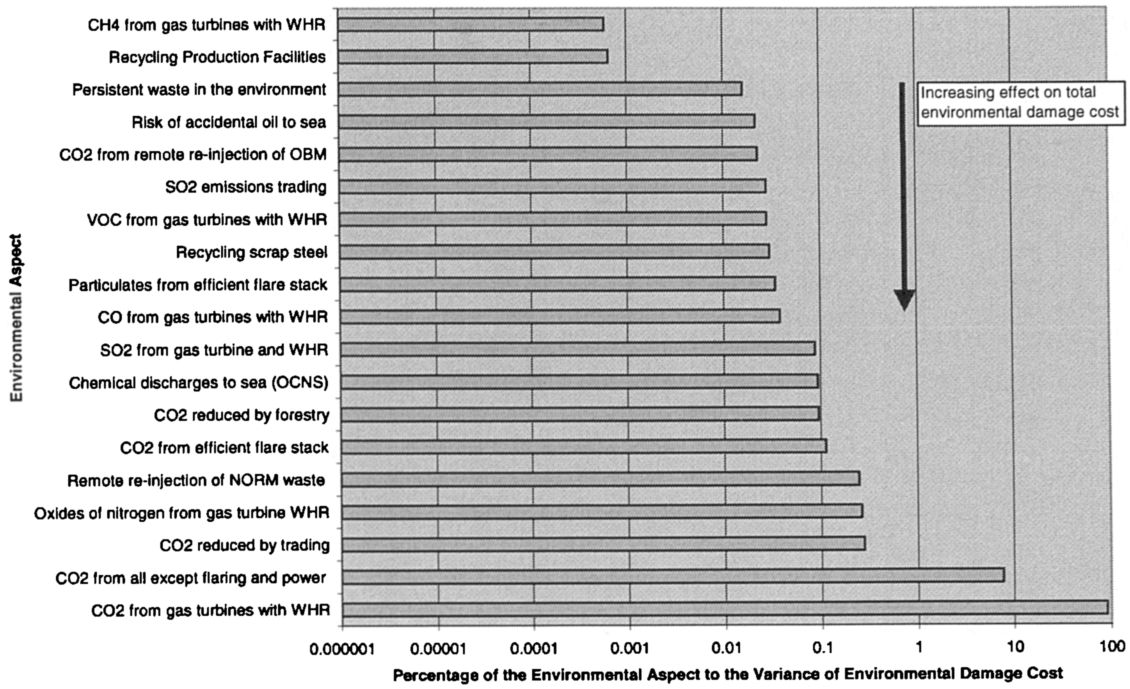


Figure 7.9. Environmental Risk Mitigation Design System *'Sbaba'* Sensitivity Analysis

The sensitivity analyses identify that it is the amount of CO_2 being produced from power generation that is the key factor in determining overall environmental performance. The environmental damage from switching from diesel to gas turbines with fired heaters is causing *Bencer* to cause slightly more total environmental damage because of the increase in CO_2 emitted, than the control (*Ebham*). If power generation is ignored temporarily, it is still the emissions of global warming gases into the atmosphere whose contribution to total environmental damage is having a greater effect than other environmental aspects. This result reflects the concern over the impact that man is having on the atmosphere (identified in Chapter 4), and would direct further improvements to reduce total environmental risk in the right direction. Afforestation and carbon trading were highlighted by the analysis as two direct techniques that were very effective at reducing total environmental damage from CO_2.

The sensitivity analysis indicates where improvements can be made to an Environmental Risk Mitigation System. All the environmental aspects that are significant have had some form of mitigation applied in the ERMS proposals except for Ebham, which has had no mitigation measures put in place to reduce adverse environmental risk. The damage associated with not acting on the significant aspects identified in the Risk Assessment phase of HEA can be seen in Figure 7.5. Marine environmental damages and damages caused by SO_2 and NO_x are contributing more significantly to total environmental damage, when compared to the ERMS proposals.

Under the HEA process, there are certain environmental aspects whose environmental damage cost is comparatively small to other aspects. However, it may be these low valued damages that could cause public protest. For example, using the best available information, the damage to whales and dolphins from the seismic survey for Field X is under £100 because the value is an expected value of damage. It is the potential of damage to whales and dolphins that could cause protest and delay a public consultation process for a field development.

7.3.2.1 Project Economics

The cost of driving down environmental risk using the Khencer ERMS has been included as a separate form of expenditure in the calculation of the Net Present Value of Field X. The expenditure has been evenly spread throughout the life of the project, except for decommissioning, because the timing of expenditures was uncertain and because it was considered that there would be little difference between annual expenditures. It is a significant additional cost. Decommissioning is the majority cost of this expenditure (£180m). Other environmental costs are minor in comparison (£9m). This total cost reflects the use of a resource that was once considered free. HEA highlights that if an operator chooses to keep on considering the environment as a free resource then not only will the Field Development programme be refused by the DTI, but that the amount of damage to the environment will not be tolerated by people in the UK.

8 Conclusions

This chapter presents the conclusions that have been drawn during the development of the new Holistic Environmental Assessment process and its application to the Field Development programme for Field X.

8.1 THE OFFSHORE OIL AND GAS INDUSTRY AND ITS INTERACTION WITH THE ENVIRONMENT

The offshore oil and gas industry has been developing the marine resources of the UK for twenty-five years. Understanding the industry's interaction with the environment is required before any type environmental risk assessment can be carried out. This thesis analyses this interaction for the whole life cycle of operations of field development, from exploring for oil and gas, to decommissioning and cleaning up the seabed after production ceases. It was discovered that interactions with the environment are many, occur at many different stages of the field development process, and transgress the boundaries of sea, air and land. It can be seen from the data presented in Chapter 2 what the scales of these interactions are. Interactions with the environment are termed as Environmental Aspects in accordance to the Environmental Management System (EMS) ISO 14001. The key environmental aspects of each phase of the field development process are summarised below and present the environmental performance of the industry.

8.1.1 Seismic Surveying

Seismic surveying generates noise pulses with very high peak levels, about 255 dB rel 1 μPa at 1 metre with a wave peak to peak time as long as 6 milliseconds. High and low frequency energy is present in the pulses at considerable magnitude ranging from below 100 Hz to 22 kHz. Local oceanographic factors affect the propagation of the sound and determine the level at which it will be received by a pelagic or sessile animal. These factors vary and so too do the location of pelagic animals, both of which reduce the certainty over which a prediction can be made about the environmental impact of received sound levels. The Joint Nature Conservation Committee and Fisheries Research

Services guidelines suggest adopting the precautionary principle to minimise this potential hazard to marine wildlife from loud underwater sound.

Studies into the effects of the sound from seismic survey on marine animals (whales, dolphins, seals, and commercial fish) will continue due to the uncertainty in this area about the level of impact. The sound from seismic shooting does produce a response in these animals but how significant these responses are to an animal's physiology or population dynamics requires further investigation. The best approach is one that is precautionary and locates any animals at risk and avoids hazardous interaction.

8.1.2 Drilling

Sea-based improvements are being made in the drilling phase of offshore oil and gas field development. The discharge of oil-based cuttings to sea no longer occurs and alternative land-based disposal options for them are being sought. Discharges of synthetic drilling muds are being phased out, and like OBMs, alternative land-based disposal options for SBM contaminated cuttings are being sought. The reduction in both types of mud increases the use and demand of water-based alternatives. The majority of chemicals used in WBMs are OCNS Group E.

There are no publicly available data to identify trends in atmospheric emissions over the same period that the reduction in sea-based discharges were being achieved. During drilling operations the major source of atmospheric emissions is fuel gas, which accounts for almost 60% of CO_2 emissions. The flaring of gas is a better environmental option than releasing hydrocarbons straight into the environment. The conservation of natural resources is, however, paramount and flaring should be prevented wherever it is safe, economic and technically feasible to do so. Sound from drilling is generally weak and continuous, and is inaudible at ranges beyond a few kilometres.

Oil-based muds are no longer discharged into the sea, and soon synthetic-based muds will not be due to offshore environmental regulation. Their disposal onshore will focus the best available techniques to dispose of contaminated cuttings. The discharge of water-based muds will still attract attention because of the organic compounds that they contain, and their potential contribution to the eutrophication of the North Sea. Further assessment into drilling fluid use and disposal, and associated environmental damage would identify what the best environmental options are. In certain circumstances these may conflict with law and public opinion.

8.1.3 Production

The total amount of oil entering the marine environment from production activities is increasing however the concentration of oil-in-water when it enters the sea is decreasing. For three years the average oil in produced water content has been below 30 ppm in anticipation of a more stringent environmental standard. This is below the legal limit of 40 ppm. Production water-soluble chemicals dissolve in the produced water and are discharged into the environment. They are highly toxic and concerns over marine environmental pollution will focus efforts to reduce their discharge or promote the use less toxic production chemicals. Since 1996 the industry has been reducing the use of hazardous chemicals by increasing the use of those that are OCNS Group E standard and using less of those with an OCNS Group A standard.

There are insufficient data to identify trends in atmospheric emissions from production operations. Fuel gas is the greatest source of atmospheric emissions and contributes to the greatest proportion of CO_2 emissions from offshore oil and gas production emissions, and that flaring is a better environmental option than releasing hydrocarbons straight into the environment. There were insufficient data to identify trends over waste returned to shore and no data were discovered on the amount of sewage and domestic wastes discharged into the sea. Underwater noise levels from production operations are considered to be low, steady and not very disturbing.

Persistent waste in the environment is an issue of growing concern because it has the potential to do more immediate damage than any other environmental aspect. The industry complies with strict Duty-of-Care regulations for the disposal of wastes. In the event of an accidental loss of persistent waste, there is no statutory obligation to report the loss to the Department of Trade and Industry. While such losses are not always unavoidable at sea, it is perhaps ironic that so much control is focused on other marine environmental aspects and not this one. Plastics, ropes, sheeting and old seismic cables are effective at injuring and killing wildlife.

8.1.4 Transportation

Pipelines are used extensively across the UKCS to transport oil and gas. The majority of chemicals used in flushing the pipeline prior to commissioning are in the low-hazard OCNS Group E. No data were discovered that quantified the emissions from transporting oil by shuttle tanker so that this could be compared with those from the energy required to drive oil through pipelines where the pressure does not permit natural flow. The environmental risk posed however, by transporting oil through well-maintained and documented pipelines, is widely accepted to be smaller than the environmental risk posed by tanker transportation.

8.1.5 Decommissioning

The OSPAR legislation requires complete removal of all new oil and gas installations and for the majority of existing ones. The peak years of decommissioning are forecasted to occur between 2005 and 2010. It is expected that at this time 32 oil and gas platforms will be decommissioned. Environmental risks lie in the possible release of residual oil, slops and sludge from the storage facilities during partial demolition or toppling of the shaft using explosives. The use of explosives offshore will require a precautionary approach to avoid causing injury or death to a marine animal from shock waves. Reuse, recycle or disposal on land whenever possible are now the major and preferred disposal requirements. The decommissioning of pipelines is not required under UK national law. Old abandoned pipelines may act as fish aggregating devices but are a hazard to other uses of the sea. Operators are therefore proposing to remove pipelines from the seabed to reduce the risk they pose to trawlers except in instances where they are buried.

8.2 ENVIRONMENTAL PERFORMANCE CHALLENGES TO OFFSHORE FIELD DEVELOPMENT PLANNING AND MANAGEMENT ISSUES

Environmental legislation is implemented to control the industry's level of interaction with the environment. The thesis explores this relationship to identify its effect on offshore operations and to discover what challenges there are for operators to control their impact on the environment, and how such information may be represented in the Holistic Environmental Assessment process. It was discovered that UK environmental legislation is in a state of change and the evidence suggests that subsequent environmental legislation will become tougher and have an increasing influence on offshore oil and gas field environmental planning and management. This is currently presenting, and will increasingly present, a new set of challenges to those involved in the development of oil and gas fields.

8.2.1 Environmental Research

A review of environmental research relevant to the offshore oil and gas industry was undertaken in this study to identify the challenges to those involved in the development of oil and gas fields. From the literature search in Chapter 3 it is clear that considerable research has been dedicated to protecting the marine environment. This is a direct result of offshore environmental legislation being focused on the marine environment. The studies carried out in this area were dominated by assessments of the effects of: oil spillage from accidents; oil pollution; and clean-up methods, on habitats and species. Studies on the impact of chemical spillage from offshore oil and gas installations were less numerous by comparison and tended to be confined to petroleum engineering journals. There was also significant research into: achieving compliance with legislative controls; the technical and economic feasibility of platform disposal options; and various ecological surveys. By comparison, considerably less research had been carried out in the other important areas, which included: environmental risk assessment; waste management; environmental management systems and auditing; environmental economics; atmospheric emissions; and sustainable development. Environmental risk assessment and economic research concentrated on oil spillage. Waste management research concentrated on the waste material returned to shore for disposal. This did not represent the total amount of research in waste management as 'marine discharges' and 'atmospheric emissions' are other forms of generated waste from offshore oil and gas activities. Environmental management systems and auditing research focused on identifying performance indicators and benchmarking. Atmospheric emissions research involved identifying technologies to reduce them, which was primarily undertaken by industry. And finally sustainable development research involved identifying sustainable strategies for operations.

This analysis of research reflects the current understanding on the industry's adverse interaction with the environment, how it is being minimised and where the challenges lie to minimise it further. The areas where considerably less research had been carried out highlighted where principal challenges lay ahead.

8.2.2 A Dynamic Environmental Agenda

The breadth of environmental challenges identified by the above is shown in Figure 8.1. With environmental assessment legislation requiring an assessment of transboundary and cumulative environmental impacts, the marine, terrestrial and atmospheric ecosystems are no longer considered as separate ecosystems. An understanding of the interconnectedness of ecosystems is emerging from climate change science. Consequently, the business of environmental planning and management in the offshore oil and gas industry is becoming holistic.

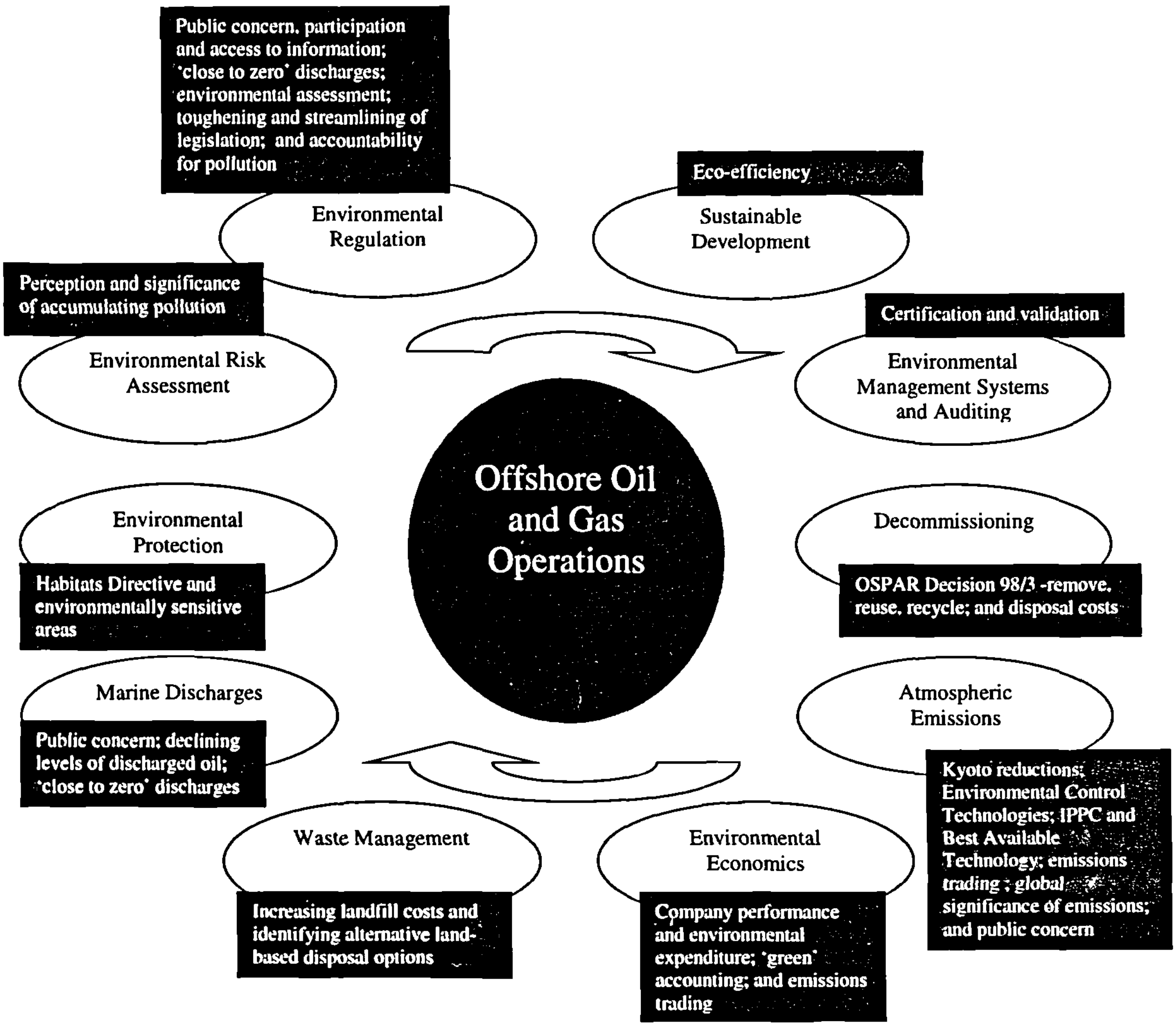


Figure 8.1. Emerging Environmental Challenges and Areas of Particular Interest

(IPPC: Integrated Pollution Prevention and Control; OSPAR: 1992 Oslo and Paris Convention on the Protection of the Marine Environment of the North-East Atlantic)

8.2.3 Tougher Environmental Legislation

It is clear from the research and consultation process that there has been, and will continue to be, an increase in environmental legislation and regulation specific to offshore operators on the UK Continental Shelf. The increase in the amount of environmental regulation is due to the increasing number of European Union Directives and OSPAR Commission Decisions. There are draft Directives and Decisions yet to be implemented into UK law. This is creating uncertainty in the industry over what standards need to be complied with in the long-term, which forces it to develop its own higher standards. There is a risk that there will be an over abundance of environmental laws making their implementation bureaucratic and ineffective at improving environmental quality. There is a need for a clear, comprehensive and flexible environmental regulatory framework for industry. It needs to be flexible enough to account for innovative techniques for environmental risk mitigation, whilst not ruling out others on social and political grounds. The collection and transportation of oil-based mud cuttings from one country to another for treatment is an example of where law is having a negative impact on the environment.

8.2.3.1 Principal Legal Developments

The main pieces of legislation which have been recently introduced in the UK are: the Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations 1999; the Oslo and Paris Convention Decision 98/3 on decommissioning; the Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998; and the Merchant Shipping (Prevention of Oil Pollution) (Amendment) Regulations 1997. The increase in legislation is highlighted above. Whilst environmental regulation is essential, it is administrative and therefore costly to business. If investment is directed toward administration, less will spent on engineering solutions. Other quality-control based methods, such as environmental management systems, may be more pro-active at controlling environmental performance. If an operator applies its own higher environmental standards through such a system then it reduces uncertainty and allows the investment to be focused on environmental risk mitigation.

8.2.3.2 Public Concern & the Law

Public concern is influencing the progression of environmental legislation from voluntary to mandatory. Society is increasingly playing a role in the development and implementation of that legislation. Public consultation is required for field developments seeking a production licence under the Offshore Petroleum Production and Pipelines (Assessment of Environmental Effects) Regulations 1999. Decommissioning standards are implemented using voluntary global guidelines from the International Maritime Organisation however tougher standards now exist in the Northeast Atlantic. The Oslo and Paris Convention Decision 98/3 prohibits the dumping, whole or partial abandonment of disused installations in the Northeast Atlantic and thus requires complete removal except for very large structures. The UK is legally bound by the convention and therefore strictly enforces its principles. This legislation will have a major effect on a field's project economics. This is because decommissioning costs are high (in excess on £100 million for a steel platform) and incurred at the end of the field when revenues are at their lowest.

The European Union, the Oslo and Paris Commission, environmental lobby groups and public concern, have a significant impact on the development of the offshore environmental regulatory regime. This thesis identified that although people are primarily concerned with marine pollution at the moment it appears that atmospheric pollution will be the next major environmental issue. This is due to concerns over health effects from ozone layer depletion and localised air pollution, skin cancer and asthma, and the global impacts of climate change.

8.2.3.3 Future Legal Developments

It appears from this research that the following regulatory developments are likely to occur in the near future: the introduction of the Habitats Directive into the licensing system; the Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2000 (in draft); and, the statutory reporting of chemical use under the Harmonised Mandatory Control System.

Post Kyoto regulatory and economic developments and societal concern over atmospheric pollution, will increasingly focus efforts on reducing the emission of global warming gases. The introduction of an energy tax to help achieve this appears to be imminent, however it will not target the upstream oil and gas industry. The key economic mechanism for reducing greenhouse gases from offshore field developments will be the trading of emissions. The industry looks set to continue developing technologies and techniques to reduce emission levels into the air. Marine pollution prevention and control will continue to be tightly regulated. The UK Government agreed at the Ministerial Meeting of the Oslo and Paris Commission, that they will strive to achieve a cessation of discharges, emissions and losses of hazardous substances by the year 2020. Such an expectation of a 'clean production' approach by industry has, and will continue to, stimulate the design of offshore field developments and exploration activities that drive down environmental impact. The European Commission's Directives and Oslo and Paris Commission's recommendations adopt an 'emission-standards' approach, which is incorporated into UK legislation. The 'clean production' and 'emission-standards' approaches will drive the continual expansion of the world market for 'Environmental Control Technologies'.

8.2.4 The Need to Manage Environmental Information

It is clear from this research that individuals' perceptions about the state of the environment are changing and influencing the way the UK offshore oil and gas industry is environmentally regulated and managed. This change coupled with the uncertainty over how resilient the environment is to perturbation presents a need to clearly manage environmental information. Such information needs to be presented in a format that is best suited to the needs of the engineer so that adverse environmental risk may mitigated against cost-effectively. The Holistic Environmental Assessment process introduced for the first time in this thesis is designed as a system of environmental risk analysis that achieves this.

8.3 HOLISTIC ENVIRONMENTAL ASSESSMENT

8.3.1 The Need for a Wider Assessment Procedure

It is clear from Chapters 3 and 4 that in the UK, environmental regulation of the offshore oil and gas industry is becoming both wider in its scope and tougher in its implementation. Public concern for the environment is increasing, with individuals expressing that they are 'very worried' about certain issues. The principal current concern focuses on pollution of the marine environment and principal future concern on atmospheric pollution at local and international levels. The issues affecting environmental quality that concern individuals the most are those that are perceived to have an effect on their health. The Brent Spar case study and criticism of the Norwegian Environmental Impact Assessment based system are two examples of how the concerns of people can widen the scope of an environmental analysis and change the law, making the 'polluter' accountable. Increasingly, people's expectations and perceptions are being considered in environmental evaluation. This was evident in BP's approach to assessing significant environmental aspects for the Schiehallion Field Development detailed in Chapter 2. BP used a screening process that classified environmental aspects that were perceived by the public to be damaging, as significant.

Greenpeace challenged the Secretary of State for Trade Industry for failing to administer the Habitats Directive into the 19th Offshore Oil and Gas Licensing Round and therefore apply it outside UK territorial waters. The case decided that UK regulations had failed to lawfully implement the Directive. This judgement favours the use of the precautionary principle particularly in matters of substantial public importance and may therefore be significant in terms of future environmental protection and case law. Consequently, companies will be looking to adopt broader approaches to assess their burden or 'footprint' on the environment. As companies become competitive and aim to demonstrate clearly to their shareholders the risk that their operations pose to the environment, reporting may change from being on an asset-by-asset basis to that which assesses total risk.

Organisations such as the British Medical Association, European Oilfield Speciality Chemicals Association, the Royal Ministry of Petroleum and Energy (Norway) and Shell Expro now recognise that a holistic approach is an integral part of assessing total risk. Even though the organisations differ on their interpretations of a holistic approach, it is quite clear that such an approach is required, particularly one that identifies all the environmental risks posed to society. Environmental risk and the potential environmental damage can be accounted for to allow companies and policy makers to assess the costs and benefits of a development. There is a risk that, because there are environmental effects that are not scientifically fully understood, satisfactory valuation in monetary terms of total risk may not be achieved.

8.3.2 A New Environmental Appraisal Tool: Holistic Environmental Assessment

Holistic environmental assessment (HEA) is a goal orientated process that utilises knowledge from all available sources and disciplines. It attempts to give an accurate account of the total environmental risk to society arising from all phases of a process designed for the manufacturing of a product and/or provision of service. It aims to ensure that, in a competitive global market, strategies to reduce one type of pollution do not lead to the production of another type.

HEA provides the basic knowledge to design cost-effective and eco-efficient field developments by: breaking down the life cycle of operations; identifying the environmental aspects of each activity in that life cycle; the environmental laws that must be complied with; and the techniques that are available to minimise environmental risk posed by environmental aspects. HEA identifies which environmental aspects for a specific field development programme are significant from historical and modelled data and prioritises them using the As-Low-As-Reasonably-Practicable principle. The damage that they cause is quantified using monetary values from environmental-economic studies. They are plotted as normal distribution curves because for many of the aspects the mean is unknown, and so only a range of values is available. All the distributions can be combined using Monte Carlo Analysis and plotted as a cumulative probability distribution function curve. From this a total environmental damage cost for a field development without mitigation is predicted with 95% confidence. Various proposed Environmental Risk Mitigation Systems (ERMS) designed to tackle all the identified significant environmental aspects, are then assessed on the basis of their impact on the field's total environmental damage cost. Two other indicators are used to assess this performance: environmental benefit (the difference in environmental damage cost between a field development programme with and without mitigation); and, the cost of the ERMS. This information together with any environmental aspects that cannot be quantified is used to decide upon an ERMS for the field development programme. The impact of the ERMS on the field's project economics is then assessed using the economic indicators: Net Present Value and Internal Rate of Return.

HEA is unique because the risks posed by environmental aspects are assessed in relation to other activities in a chosen geographical area to assess total environmental risk, and suggests strategies to reduce that risk. The benefits of carrying out the assessment include:

- transparency – the identification of linkages will be particularly useful when assessing waste disposal and options for by-product synergy and re-use

- knowledge management – opportunity for and cost-benefit of sharing environmental information
- expectation management – identification and incorporation of public concerns
- environmental liability identification – reducing the risk of overlooking any potential liabilities
- sustainable development – HEA could be used to measure progress toward sustainable development

8.3.3 Current Tools and Instruments Fail to Appraise Critical Issues including Total Environmental Risk

Various techniques are available to assess how the industry can drive down its environmental impact and comply with environmental regulation. Environmental Assessments (EA) required by European law do not cover the whole life cycle of the project that they are analysing. Life Cycle Analysis (LCA) was developed to assess the environmental loadings of a product, process or activity over its entire lifecycle. It was the first technique used in environmental analysis that adopted what was described as a holistic approach. It fails this approach by not assessing accidental emissions or environmental impacts other than those that are direct. Cost Benefit Analysis (CBA) offers the opportunity to value environmental effects and appraise a project on the basis of costs and benefits. Not all environmental effects can be valued and of those that can there is considerable uncertainty in their valuation and occurrence. CBA cannot satisfactorily measure the total environmental risk of a project. Consequently there is a need for a technique that overcomes the failures of project-level EA, LCA and CBA, and assesses total environmental risk. The Proposal for Strategic Environmental Assessment, as a tool for integrating environmental concerns into planning and programming, is an important step toward a broader environmental appraisal that includes social and economic aspects. However, its aims and objectives differ from HEA.

8.4 APPLYING HOLISTIC ENVIRONMENTAL ASSESSMENT

HEA is a design tool that guides the environmental engineering of a field development before any Environmental Statement is prepared. Once an Environmental Statement is required, much of the information from the HEA, particularly the environmental risk assessment and the analysis of alternative design systems, can be used. HEA will also identify which environmental risk mitigation techniques are best suited to the field development, and which can be improved on to keep ahead of environmental standards.

It is designed to be a multi- and transdisciplinary 3-staged process that allows the development of an environmental accounting system to measure both the economic and environmental performance of a Field Development Programme with different Environmental Risk Mitigation Systems. The field development's potential environmental aspects are quantified using monetary values. There is uncertainty associated with their use either because for some of the environmental aspects valued very few valuation studies have been undertaken, or because for others there are so many complicated environmental risks associated with them that they produced a wide range of values. For this reason, and because they are non-market values, environmental damage costs must still be treated with caution and not internalised into project economics. Their use in HEA is attractive because they introduce a second tier to the assessment of environmental risk. The qualitative risk assessment prioritises risks on the basis of what needs to be acted upon whereas the environmental accounting system identifies once mitigation is in place (or in the event of a lack of) which environmental aspects are causing the most damage to the environment. This information is useful to identify where the most cost-effective improvements can be made to drive down total environmental risk, and which actions are transferring risk elsewhere. Not all the environmental aspects can be quantified and further research needs to be undertaken to account for these. For the meantime the qualitative risk-based weighting is used for unquantifiable aspects. Also not all of the environmental impacts associated with a particular environmental aspect have been valued. This has been combated in this study by using broad factors to value damage, see section 5.4.4.2. Also, with increasing confidence from the more research into and use of these environmental damage costs (they are already being used in Environmental Damage Valuation in the US), such values will be useful indicators.

8.4.1 HEA of Field X – a real case study Field Development Programme

The HEA process is able to indicate whether or not the proposed oil and/or gas field development poses significant environmental risk, and if so where, what and how much will it cost to mitigate this risk, and which areas after mitigation can be improved upon to enhance environmental performance.

The analysis of the different Environmental Risk Mitigation Design Systems, *Ebham, Khencer, Bencer, Wosta* and *Sbaba,* identified that *Khencer* was the most cost-effective and eco-efficient proposal put forward. All highlight that the main factor for controlling total environmental risk is the amount of carbon dioxide being emitted. The contribution that carbon dioxide makes to the variance in total environmental damage cost suggests that by lowering cost-effectively the level of carbon dioxide a field produces, an operator will achieve substantial environmental benefit.

The analysis highlights that any activity will produce some level of environmental damage. It is the level of mitigation activity that must be considered when proposing strategies to mitigate environmental risk. The HEA process does not promote 'extreme' levels of mitigation activity in an environmental risk mitigation system (such as transporting cuttings to a remote location). Instead it encourages few and low impact techniques of environmental risk mitigation. It will for this reason strongly favour change in field designs that limit the need for mitigation activity.

The HEA process is also able to identify changes in pollution from different environmental risk mitigation techniques. This was evident in the change in power generation between Khencer and Bencer from diesel to gas turbines with fired heaters, proposed to reduce SO_2 and NO_x emissions but resulted in an increase of CO_2 emissions.

The UK is committed by ratifying the Kyoto Protocol to lowering carbon dioxide levels due to the growing consensus of scientific agreement that global warming from carbon dioxide is potentially such a serious problem that action, even if precautionary, must be taken. The HEA carried out for Field X confirms this. The damage caused by releasing large quantities of carbon dioxide is so considerable that all the other environmental aspects pale into insignificance. The damage value for carbon dioxide is still uncertain and it must be remembered that it is an essential compound for photosynthesis and hence life on earth. The author is concerned that goal of HEA would be undermined, if an operator focused purely on the finding based upon carbon dioxide environmental damage costs, and invested solely in reducing carbon dioxide levels.

The application to Field X demonstrates that HEA is a useful design tool and that is not designed to replace the any other environmental appraisal tools, nor their objectives.

8.5 TERMINOLOGY

The use of terminology and the introduction of new terms in environmental science is evolving quickly. Environmental risk now focuses on all forms of environmental change whether they be short, medium or long term changes. Terminology needs to develop with the demands of a clean production approach to promote transparency and avoid confusion over *what is* and *what is not* environmental quality. Environmental quality is no longer solely a measure of the amount of pollution in an area but rather the ability of the environment to support all life forms and particularly humans that now endeavour toward sustainable development. Sea level change is an example of changing environmental quality in the 21^{st} century. Its impacts are irreversible and costly.

8.6 RECOMMENDATIONS

8.6.1 Recommendation 1: Standardising Environmental Accounting.

The HEA process will benefit greatly by a formalised and standardised approach to preparing environmental accounts. This would involve assessing whether or not the environmental damage costs should be discounted. There are pros and cons of discounting values for environmental resources. Few studies consider the value of pollutants. Whether the damage cost generated by an environmental aspect increases or decreases, per unit of output, as an affected environmental resource becomes scarcer is an area worthy of further study.

8.6.2 Recommendation 2: Integrating Social Impact Assessment

The HEA process already assesses social impacts of field development by addressing concerns and using environmental damage costs that are socially-based. However there is still considerable research that could be done in this area so that social aspects can be incorporated into the HEA process.

8.6.3 Recommendation 3: Field testing and Standardising HEA.

The choice of environmental damage estimates and how many of them to include is subjective. This is just one example in HEA of where differences in establishing boundaries for assessment may occur. The HEA process recommended by the author may be developed further to include guidelines, and become refined with practice, resulting in the adoption of an international standardised approach.

8.6.4 Recommendation 4: Ensuring Teamwork in HEA

It is suggested that a multi- and transdisciplinary team undertake an HEA. The assessment process will be most effective by members of the team working together towards their stated project goal and not by producing separate reports that are later integrated together to produce an integrated environmental assessment.

8.6.5 Recommendation 5: Standardising Environmental Damage Costs.

Further work needs to be conducted to expand databases of Environmental Valuation Studies like the Canadian Environmental Valuation Resource Inventory. A large database would provide enough information to work towards standardising accurate environmental damage costs for particular environmental aspects.

8.6.6 Recommendation 6: Correlating Environmental Damage Costs and Risk-weighted Values

A statistical correlation analysis could be undertaken to test whether there is any correlation between the ranking of environmental aspects by risk assessment and those ranked on the basis of their damage cost.

8.6.7 Recommendation 7: Verifying or conducting a Value for Money Audit of 'best available technology'

'Best available technology' (BAT), it's definition, as it stands, may lead to different interpretations depending upon what an individual assigns as BAT. Adopting an environmental technique verification programme similar to that implemented by the US Environment Protection Agency, whereby BATs are chosen on the basis of their proven performance on minimising risk to the environment cost-effectively may solve this. This will avoid technology fraud. It will be particularly useful where environmental targets and regulation are changing and companies have to achieve these targets to maintain their certification to ISO 14001 and EMAS.

8.6.8 Recommendation 8: Conducting a HEA with Energy Values

Energy-based HEA: Energy units are increasingly being adopted as a measure of environmental performance. These rely on the assumption that the less energy wasted by a project then the less environmental impact it will cause. Energy levels are blunt and cannot equate or distinguish environmental impacts, whether they are acute toxic effects to a population, or the loss of endangered species or rare and sensitive habitat. A study that assessed the energy efficiency of a project and the total environmental damage of a project under the HEA process could produce an interesting environmental performance indicator to be tested. One that details the amount of damage caused per unit of energy expended or environmental benefit per unit of energy saved.

8.6.9 Recommendation 9: Developing HEA Software

Software development: Much of the information required by HEA could be presented in a quick and user-friendly format. This may be achieved by developing an expert-based environmental software system. Engineers who prepare Field Development programmes could use the software. Such a service would enable operators to donate less time and money gathering environmental information and more on the design and engineering of a field. The HEA tool would have to be routinely updated to incorporate engineering, environmental, economic and legal information.

8.6.10 Recommendation 10: Assessing the Benefits of Environmental Investment

This study shows that the environment is a significant cost. Essential because without it the UK government and European Commission will not permit development where environmental law will be broken. However, the benefits of 'good' environmental performance are less tangible. Future studies need to be conducted to assess the benefits of environmental investment in field development to operators in the longer term.

8.6.11 Recommendation 11: Study into Assessing the Effects of Introducing Tax Incentives for Investment into Environmental Risk Mitigation Techniques other than Decommissioning

The research identified that the corporation tax relief for decommissioning capital expenditure is 100% for all new platforms. Scientific Research also qualifies for the same level of relief. This research identified that there is a need for an incentive to invest in driving down environmental impact. The author proposes that a study is conducted that assesses the benefits of introducing a 100% tax relief for Environmental Technologies to offshore oil and gas field development.

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Annex 1

ENVIRONMENTAL ASPECT MODELS

Environmental Aspect	*Modelling Effects*
1 SOLID MATERIALS	
1.1 PRESENCE; Visual and Physical	*An Environmental Statement is required under the Assessment of Environmental Effects Regulations 1999, if the distance to coast is: less than 40 kilometers, Special Area of Conservation or Special Area of Conservation; less than 20 kilometers of concentrations of birds considered internationally important; or close to important archaeological features.* *Quantitative analysis of natural communities can be derived from the interpretation of photographs, or by sampling, using undisturbed quadrates. Photography has the limitation that only sessile species may be identified. Monitoring surveys, in situ, and the analysis of collected samples can highlight the intensity and extent of impact from operations. Diversity indices such as the Shannon-Wiener index (H_s) and the use of multivariate analysis have long been used as a measure of environmental health. The assumption behind their use is that communities with high diversity result from less environmental stress than those with low diversity (Kingston, 1992).*
1.2 TURBIDITY & SEDIMENTATION	*The zone of effect is dependent on a number of factors including particulate type, settling velocity, water depth, release depth and local hydrodynamic conditions. Lateral spreading will be less than down current spreading. Assuming settling velocities of 0.2 m/s for gravel, 0.02 m/s for sand and 10^{-5} m/s for clay and silt. A release of 75m above seabed with a 0.5 m/s current (~1 knot), will produce a 500 m for gravel, 5,000 m for sand and widespread clay and silt deposition.* *The biological significance of the effect depends upon whether natural sedimentation disturbance and accumulation rates are high or low. Thus the sensitivity of the environment will influence the significance of the effect. In areas where turbid waters are common place few effects if any will be seen. Thus turbidity is a problem in areas where benthic ecosystem is sensitive and reliant on continuous light. This is relevant to tropical areas where coral reefs rely on their inhabiting zooxanthellae to photosynthesize, to survive.* *Water Column sampling at various depths, using chromatographic and spectrographic analysis of collected suspended matter to record levels of chlorophyll, Adenosine Tri-Phosphate and other substances including trace metals, will identify changes in biological activity from discharges. The same method, including the use of gas chromatograms, can be employed for bottom sediment analysis obtained by grab/core sampling.* *Sedimentology observations in any study area will indicate scour and deposition by bottom currents enabling predictions to be made over the fate of contaminated material.*
1.3 HEAVY METALS	*Dose-Response Assessment – a mathematical relationship between the amount of toxicant that a human is exposed to and the risk that there will be an unhealthy response to that dose. Dose response curves and the methods used to apply them are quite different for carcinogenic and non-carcinogenic effects.* *Water Column sampling at various depths, spectrographic analysis of collected suspended matter to record levels of trace metals from discharges. The same method can be employed for bottom sediment sampling.* *Modelling the impacts of trace metals from drilling fluids can be achieved using PISCES - the Pollution Information System for Contaminants in Estuaries and Seas see 3.3.*

1.4 EXPOSURE TO NORM WASTE	The ExtemE Project Ecosense Model assesses the health impacts from seafood consumption of extremely, long-lived, slow depositing radionuclides (H-3, C-14, I-129, I-131, Cs-134, Cs-137, U-234, U-235, U-238, Pu-238, & Pu-239). However, NORM waste produced offshore contains radioactive material that occurs in nature. Such waste has a specific activity of 131 pCi/g for ^{226}Ra. Average annual radiation exposure of such waste to workers in Texas trained to dispose of such waste is 4 mrem. Regulations require exposures to workers not exceed 5,000 mrem within a given year and to the public, exposure cannot exceed 100 mrem during any single year. Public exposure was determined to be 20 mrem for the NORM processing/disposal facility. The higher value to worker exposure is based on the assumption of 100% occupancy at the perimeter fence of such a facility. Risk analysis determines that such exposures would lead to a reduction in lifetime expectancy of 0.2 days for workers and 0.8 days for the public. Figures may be compared to the risk of being 15% overweight where consequently life expectancy is reduced by 2 years and to the reduction in life expectancy reduction from an average exposure of workers to artificial radioactive material, which is 15 days (Lyon et al., 1997; Cohen & Lee, 1991)..
1.5 SEABED DISTURBANCE	If operations occur fish spawning and nursery grounds then an Environmental Statement may be required under the Assessment of Environmental Effects Regulations1999. Physical disturbance is usually restricted to within 20 m of the line or activity, although sedimentation may occur over a larger area. Anchoring may extend up to 1-2 km from the central location. This would be less in shallower water. Anchors may drag for hundreds of metres before settling. Not all benthic communities are equally affected. It is more difficult to detect effects in areas where sediments are highly mobile, while boulder or pebble habitats are more vulnerable. Not all seabed areas are characterised by rich epifuanal communities and thus activity does not beyond reasonable doubt necessitate significant seabed activity. Such communities occur as a mosaic of small patches in the seabed making them difficult to find.
2 ENERGY	
2.1 NOISE IN AIR; Disturbance	Some marine mammals occur on land – pinnipeds and sea otters – commonly occur on land and emit aerial calls. Sound from an ominidirectional source in an unbounded uniform atmosphere will be attenuated by spherical spreading: $Lr = Ls - 20\log R$ Where Lr = the received level in dB re 1µPa Ls = is the source level @ 1m in the same units (as above) R = the range in metres Source: Richardson et al., 1995 The effects from noise in air are dependent upon the source, the ground and weather conditions. In the case of helicopters flying over water, air-to-water soound has been documented using wave theory (Weinstein and Henney 1965, Medwin and Hagy 1972) and ray theory (Hudimac 1957, Urick 1972, Waters 1972, and Young 1973).

2.3 NOISE IN WATER; Underwater explosives & Vibration	*Water is a good transmitter of sound energy and as such sounds travel long distances underwater. Shallow water transmission (depths less than 200m) of sound is affected by many factors making it difficult to develop adequate theoretical models. Consequently site specific data is combined with theory to develop reliable propagation predictions (ARPA & NMFS, 1994). In deep water (>2000m) with nearly no boundaries or absorption loss sound will spread spherically. Where it is trapped between horizontal refracting or reflecting layers it will spread cylindrically:* $$Lr = Ls - 10LogH - 10LogR$$ *Where* *Lr = the received level in dB re 1µPa (underwater)* *Ls = is the source level @ 1m in the same units (as above)* *H = the 'effective' channel depth* *R = the range in metres* *Source: Richardson et al., 1995* *The audible range of underwater noise is dependent upon the hearing of individual species. Theoretically, audible levels may be transmitted up to 100km from the source. The level of effect is dependent on the frequency and intensity of the noise. Sounds audible to fish and marine mammals may not be audible to man and vice versa. A 'noise-effected' species may be attracted to the source, repelled or show no visible or physiological response. Noise from drilling and production is considered unlikely to have an effect beyond 500 metres. Seismic sources are recommended by the Joint Nature Conservation Committee to keep a 500 m distance from marine mammals to avoid and minimise the potential of an environmental effect. UK Fisheries Agencies have identified seismic sensitivity periods to identify exclusion windows (as a precautionary measure) to minimise seismic disturbance to commercial fish spp. at or around peak times and locations of spawning periods (Fisheries Research services et al., 1998).* *Modelling predictions may be useful for planning and preparing environmental impact assessments, but experts recommend obtaining relevant empirical data due to the highly variable and site specific nature of underwater sound, especially in shallow water and of airborne sound transmission near the ground.*

3 LIQUID DISCHARGES	*Dose-Response Assessment performed by toxicity testing – a mathematical relationship between the amount of toxicant that a human or organism is exposed to and the risk that there will be an unhealthy response to that dose. Toxicity testing can be broadened to assess the impacts of pollutants upon the structure and function of ecological systems. Dose response curves and the methods used to apply them are quite different for carcinogenic and non-carcinogenic effects.*
3.1 OIL DISCHARGES; ballast water, oil-based muds (including slugs and pills); produced water	*Biological consequences are more severe if the discharge occurs in the coastal or estuarine environment, particularly in the intertidal zone. Complete recovery of intertidal zones may take over a decade and is dependent on environmental sensitivity and the type of oil contamination.* *Fallout slicks from offshore flaring are considered to be regular features of well testing at North Sea installations. These are intermittent and of short duration. Inputs from flaring are not well quantified. There are unpublished reports that highlight that flaring contributes large volumes of hydrocarbons particularly PAHs to the marine environment. Up to 30% of Hydrocarbons flared during well testing may escape combustion and end up in the sea (Kingston, 1991).* *Petroleum hydrocarbons are removed from the sea surface by evaporation, dissolution, wave produced spray and bursting bubbles. Their transfer to the atmosphere depends on wind speed, sea state, and the extent to which wave breaking and white-cap formation are suppressed by oil films, which in turn is dependent largely on film thickness and the horizontal extent of the film. Evaporation reduces the amount of toxic components of oil entering a marine ecosystem. Hydrocarbon fractions containing less than 13 carbon atoms subject to great losses in the first few days, up to about 20 carbon atoms in the first few weeks. This process contributes to the formation of oily sludge and tar balls. Lower molecular weight hydrocarbons are also the most soluble. Thus evaporation and dissolution are competitive processes and responsible for the removal of the same types of products which include aromatics. Higher ring aromatics (e.g. PAHs) are practically unaffected by evaporation and are involved in long-term toxicity. The sea/air transfer process is temporary and most hydrocarbons will be redeposited a few metres to several kilometres from their point of transfer. Solar radiation acts as a catalyst for transfer and assists in the breakdown of products when airborne (GESAMP. 1977). Consequently the modelling the fate of oil is complex.* *Polludrome – a dedicated hydraulic canal in which various marine and inland water environmental conditions can be simulated to predict the behaviour of oil and other pollutants in marine and inland waters. The natural weathering processes of evaporation, dispersion and emulsification processes can be recreated and modelled (Merlin, 1998).* *OSIS v3.0 – Oil Spill Information System – predicts the transport and behaviour of an oil spill. Model has been developed from data collected during full scale sea trials involving licensed experimental oil releases. The model is based on work undertaken by AEA Technology's laboratory tests assessing dispersant effectiveness and displays a time window for dispersant application for validated combinations of oils and dispersants. It does not detail the optimum time of other response options e.g. booming, skimming as BMTMIS considers that there is insufficient validation data available for a credible attempt. (British Maritime Technology Marine Information Systems (BMTMIS), 2000).* *PROTEUS – Pollution Risk Offshore Technical EvalUation System – capable of predicting the transport, geochemical and ecotoxicological impact of produced waters, speciality chemicals and drilling wastes. Developed under the Managing Impacts on the Marine Environment programme (Tyler, 1998). As a field moves into production, PROTEUS can be used to plan and manage the discharge of produced waters and co-discharged speciality chemicals. The application utilises BMT's established application framework incorporating GIS and electronic mapping and a set of data servers handling 3-D hydrodynamics, sediment transport, bathymetry etc. Specialised databases of contaminant properties and biota are included to drive the sophisticated geochemical and bio-impact models.* *EMDROPS – Environmental Management, Display and Response Operations Planning System – an oil spill management tool developed by Det Norske Veritas to: identify potential sources of pollution; environmental resources at risk; assessing damage; and, planning response actions (Johannessen, 1998). The software cannot carryout sensitivity analyses.* *SOCRATES - The Shoreline Oil Cleanup, Recovery and Treatment Evaluation System has been designed to help response personnel get access to essential information in the event of a spill by providing an on-line contingency plan, equipment registry, clean-up methodology decision support system and resource requirement calculation facilities. The SOCRATES system holds databases of the key contingency plan information which are pre-stored. These include data on the physical (beach substrate type, dimensions etc.) and operational characteristics (ability to store oil on the beach, load bearing capacity), information on the location and sensitivities of coastal economic/natural resources, details of access locations and the locations and inventories of equipment bases available. In the event of an oil spill, data on the extent of oiling and condition of the oil are derived from OSIS model runs, or directly entered by the user. The database is then scanned to provide the user with a complete description of the oil impact zone. At this stage the expert system is activated to combine the information contained in the contingency plan databases with the oil spill scenario data. The expert systems then provide advisory options for clean-up of*

	the beach with methods selection for each stage of clean-up from site access improvement through to final treatment. Based on the adopted clean-up methodologies, the expert system then combines this with information on the extent of the oiling to advise on the individual items of equipment required and the quantities needed. This is then finally combined with the equipment database inventories to identify the sources of equipment and the potential costs of the clean-up (British Maritime Technology Marine Information Systems, 2000).
	The decrease in benthic biodiversity and abundance of particular organisms has been recorded in various studies to occur at varying radii from the platform. In 1996 in a comparative study with synthetic based muds, Veil J et al., identified a zone of effect of 500m. Davies J M et al., recorded biological effects up to 3,000 m from the point of discharge. Other studies have recorded effects following elevated concentrations in sediments up to 6 km from the point of discharge 6 years previous (Olsgard & Gard 1995). *As intolerant species are lost and opportunist species in the ecosystem increase in numbers, species diversity will be reduced in the wider area. There may also be an increase in the biomass as the opportunists capable of utilising the hydrocarbons increase in numbers.*
3.2 BALLAST WATER: introduction of foreign species	*Prediction of effect is highly variable. The significance of the effect is dependent upon the sensitivity of the ecosystem to the alien species, and the ability of the alien species to survive in its 'new' environment. The number of non-indigenous species in the Central and Northern Baltic Sea 35; San Francisco Bay >150 – densities of the introduced Chinese clam in parts of the bay are 10,000 per m^2. However there may be effectively zero effect for vessels that travel short distances reducing the possibility of introducing foreign species. The potential environmental risk increases with distance particularly for vessels motoring along international shipping routes.*
3.3 CHEMICALS; produced water chemicals; sewage and canteen wastes; synthetic based muds; water based muds; & brines	*Discharges of chemicals are regulated by the DTI using a voluntary Offshore Chemical Notification Scheme (OCNS), which incorporates the OSPARCOM Harmonised Offshore Chemical Notification Format (HOCNF). HOCNF standardises the requirements for the testing and reporting of all chemicals used by operators throughout the entire North East Atlantic Sector. Chemical selection based on HOCNF data is achieved using Chemical Hazard Assessment and Risk Management Model (CHARM). Chemicals are classified into hazard groups (A-E) on the basis of environmental risk assessed using the equation Predicted Effect Concentration/Predicted No Effect Concentration (Vik, 1998). Operators are obliged to notify the Government if the tonnage limit of a particular group per well drilled will be exceeded. Chemicals in Group A are considered particularly hazardous to the marine environment and their use is strongly discouraged by the Government (Department of Trade and Industry, 1996). The model uses ecotoxicological information from algal sp. Skeletonema costatum, crustacean sp. Acartia tonsa, sediment reworker sp. Corophium volutator and fish sp. Scopthalmus maximus juvenile. Ecotoxicity – it is the dose that makes the effect. In organisms, acute toxicity by chemical substances is the amount required to kill the organism. Hence, the ecotoxicological information records the direct effect of chemicals on four species. For longer-term effects it requires other data including chemical biodegradation and bioccumulation rates according to OECD procedures. These assess the capacity of the constituents in the discharge to be eliminated or accumulated in the food chain. The models do not incorporate realistic exposure to the dose of a discharged chemical (or group of) under hydrodynamic conditions (Furuholt, 1995). Also these procedures simplify synergistic effects and do not consider the increased susceptibility of an organism to a mixture of chemicals, when exposure to a particular chemical species may weaken its physiology.* *Field tests have been used to develop formula to calculate the spread of produced water in the water column:* $$\frac{c(x)}{c_0} = Q_0\sqrt{\frac{U}{96x^3Ky^2}}$$ *where* *c0 = concentration of a component in the discharge* *c(x) = concentration at distance x* *x = distance from discharge point* *Q0 = discharge volume per time unit* *U = current velocity* *Ky = vertical diffusion coefficient (typically 0.01 m^2/s)*
	Contamination of surface waters with biodegradable organic matter will promote micro-organisms to oxidise the matter. This is known as biochemical oxygen demand (BOD), mg of wastewater per litre of wastewater and is made up in two parts: the carbonaceous oxygen demand (CBOD) and nitrogenous oxygen demand (NBOD). This occurs in both aerobic and anaerobic environments. Anaerobic decomposition can produce highly objectionable waste products including H_2S, NH_3 and CH_4. There are various BOD tests to model the impact of a given waste stream. Such tests are important to assess environmental damage in closed bodies of water. At sea measurements of oxygen close to the bottom may be obtained in situ using oxygen electrodes can provide information on field effects of hypoxia and anoxia on benthic fauna (Diaz & Rosenburg, 1995).

	It is assumed that one person produces 0.1m³ of sewage (100g fecal matter & 10g of urea) and 0.2m³ of water use contaminated with traces of oils and soaps. If we assume 100 people are present on the facility, 30m³ of sewage will be discharged with Biological Oxygen Demand (BOD) of 300g per m³. A BOD of 9 kg per day (3.3 tonnes per year) can be expected. Environmental Assessment studies identify that the fallout of organic material may increase productivity in the vicinity of the discharge point, possibly encouraging opportunist species. Meteorological and hydrodynamic factors either increase or reduce the severity and frequency of hypoxia and anoxia. In areas of good mixing the local effects of this will be negligible and limited to 100m from the discharge point. *PISCES - the Pollution Information System for Contaminants in Estuaries and Seas - is an advanced contaminant transport model developed specifically for modelling the transport and fate of trace metal and organic contaminants in marine systems. The system runs within British Maritime Technology's application framework incorporating GIS and electronic charting capability. With its highly user friendly interface PISCES is designed for use by environmental managers charged with managing and planning the waste discharge from coastal industrial plants or offshore facilities. PISCES provides a complete modelling capability incorporating hydrodynamics, simulation of master variables (e.g. salinity, temperature), full modelling of sediment dynamics. The model incorporates a complex geochemical model able to represent the behaviour of chemicals in terms of their sediment-water partitioning behaviour, volatilisation, degradation etc. A new bio-impact model allows the simulation of the uptake of contaminants to marine biota and their consequent toxic responses (British Maritime Technology Marine Information Systems, 2000).*
	Field studies predict that dilution of hazardous chemicals to non-acutely harmful levels should occur within 20-50 metres of the discharge point. However there is evidence that some chemicals may have an effect up to 500 metres in deep water. The zone of potential effect could be larger in shallower waters e.g. 1,000 metres. *The type and quantity of base fluid used in the SBM and the energy of the environmental setting into which the cuttings are discharged will affect the significance of effect. SBMs are recorded to have a greater effect on benthic communities with varying zones of effect around the point of discharge by comparison to WBMs.* *A Norwegian field study recorded a 100 m zone of effect from SBM cuttings discharge and within 1 year populations were classified as 'back to normal' (Gjos et al., 1991). In a study by Candler et al., in 1995, PAO type SBM cuttings discharged 2 years previously into 128 ft of seawater adversely affected a 50 m zone. The elevated levels of 'total petroleum hydrocarbons' (TPH) acted as an indicator of PAOs. An Australian field study in the Bass Strait identified minor long-term environmental risks to benthic fauna from the discharge of Ester SBMs. It further recorded: negligible measurable effect from elevated barium concentrations on the biota; localised biological effect (within 100 m from point of discharge); and a 4 month ecosystem recovery, attributable to biodegradation and hydrodynamic dispersion processes. Biological effects were primarily recorded as reductions in the number of taxa at Class level. Variations at family and genus level appeared variable (Terrens et al., 1998). The use of ester SBMs in the North Sea has reduced the abundance and species richness up to 3000 m from the well. These effects disappeared after one year (Dan et al., 1996). A study by Hanni et al., in 1998, identified that, assuming less than 5 g of synthetic material per 100 g dry weight cuttings, invert drilling fluids utilising synthetic base fluids do not produce a cutting pile, are low toxic, do not bio-accumulate and are biodegradable.* *The Netherlands study and others identify minor effects associated with the discharge of WBMs. It is the presence of oil in discharged drilling wastes that should be considered as a major source of toxic components and environmental degradation and responsible for the biological effects observed at OBM locations. In the Gulf of Mexico, where drilling fluids have been predominantly WBMs, effects on the benthos were localised to within 100 m of the platform (Montagna & Harper Jr., 1996).*
3.4 HEATED WATER	*The amount of water required to remove waste energy and the impact that that has on the temperature of the water can be calculated. For many environmental systems the substances being heated are solids or liquids. The change of energy stored in a system when the mass m changes by an amount T: Change in stored energy = mcΔT; where c is the specific heat capacity at constant pressure of a substance (Masters, 1990).* *As water temperature increases two factors combine to make it difficult for marine life to get sufficient O_2 from water. Metabolic rates increase, generally by a factor of 2 with each 10°C rise in temperature. This causes an increase in the amount of O_2 required by organisms. Also, the available supplies of dissolved O_2 (DO) are reduced by a faster assimilation of waste that reduces DO at a faster rate, and temperature. As temperature increases, the amount of DO that the water can hold decreases. Thus as temperature increases, O_2 demand increases and while the actual dissolved amount goes down. Thermal pollution will stimulate planktonic growth and marine fouling of structure. For certain species, eg sea trout, an increase in temperature is life threatening. For other species warmed water may be considered beneficial.*

4 GASEOUS EMISSIONS	*Emissions of gases from stacks depending upon the atmosphere may either cone, loop, fan, fumigate or loft. Computer programmes designed to model dispersion of pollutants adopt the assumption that the time averaged pollutant concentration downstream can be modelled using a normal, or Gaussian, distribution curve. The basic Gaussian dipersion model applies to a single point source.* $C(x,y)=\frac{Q}{\pi u_H \sigma_y \sigma z}\exp\left(\frac{-H^2}{2\sigma_z^2}\right)\exp\left(\frac{-y^2}{2\sigma_y^2}\right)$ *Where* *C(x,y) = concentration at ground-level at the point (x,y), μg/m³* *X= distance directly downwind, m* *Y= horizontal distance from the plume centreline, m* *Q= emission rate of pollutants, μg/s* *H= effective stack height, m(H=h+Δh, where h=actual stack height and Δh=plume rise)* *U_H= average windspeed at the effctive height of the stack, m/s* *σ_y= horizontal dipsersion coefficient (standard deviation), m* *σ_z= vertical deposition co-efficient (standard deviation), m* *Source: Turner, 1970* *The ExternE Project Ecosense Model – Analysis of Health Effects analyses from a broad range of studies including:* *Non-carcinogenic effects of air pollutants* *Carcinogenic effects of radionuclide emissions* *Carcinogenic effects of dioxins and trace metals* *Occupational health issues (disease and accidents)* *Accidents affecting members of the public (ExternE, 1998).*
4.1 CARBON DIOXIDE; METHANE	*Use of the Climate Sensitivity Parameter enables future global temperature change to be calculated from estimated future concentrations of CO_2 and CH_4 using the radiative forcing functions of greenhouse gases (Masters, 1990). Estimates for the Climate Sensitivity Parameter are difficult to make and this uncertainty is reflected in the IPCC (1996) estimate of global surface temperature change associated with a doubling of CO_2 of between 1.5°C and 4.5°C, with the best estimate being about 2.5°C.* *Emission Direct Contribution to Climate Change – Damage Modelling for the IPCC undertaken by Bruce et al., 1996 reported a range of damages from \$5-\$125 per tonne of carbon emitted in 1995. IPCC was unable to endorse any particular range or figure.*
	UKOOA Atmospheric Emission Inventory - method to estimate atmospheric emissions from E&P operations adopts a five-tiered approach. The five tiers are based upon the following principles: Tier 1 – production volume based factors; Tier 2 - fuel consumption, flaring volumes and product loss based factors; Tier 3 - emission factors for individual types of equipment; Tier 4 - manufacturers supplied data, site specific analysis, actual equipment operating conditions; Tier 5 - source testing. The emission gases that are included in the scheme are: carbon dioxide; carbon monoxide; nitrogen dioxide; sulphur dioxide, methane and volatile organic compounds (excluding methane).
4.2 CARBON MONOXIDE	*CO can adversely affect human health however there are apparently no detrimental effects on materials or plants. CO is an asphyxiant and is modelled as an amount of carboxyhaemoglobin in the blood (COH), a percentage of the saturation level, %COHb. The amount of COHb formed in the blood is related to the CO concentration and the length of time exposed: %COHb = $\beta(1-e^{-\gamma t})$[CO] where β=0.15% ppm CO; y=0.402hr-1; t=exposure time in hours; and, [CO] is carbon monoxide concentration in hours.*
4.3 OXIDES OF NITROGEN; SULPHUR DIOXIDE; PARTICULATES	*The ExternE Project Ecosense Model – Industrial Source Complex Model (ISC), a Gaussian plume model developed by the US-EPA to model the transport of primary air pollutants (SO2, NOx and particulates) on a local scale (ExternE, 1998; Brode and Wange, 1992)* *The ExternE Project Ecosense Model – no single method was recommended to model air pollution damage to forests from critical loads exceedance and acidification of the soil. It was suggested that a link between cause (critical loads exceedance for acidity) and effect) reduced timber growth) can be traced using simple data, rather than complex models (ExternE, 1998).*
	Pearce & Crowards Health Effects Model – uses epidemiological meta studies to assess the health impacts of small particulate matter including premature deaths and morbidity impacts (Pearce & Crowards, 1996).
	The ExternE Project Ecosense Model – The Windrose Trajectory Model, a user-configurable trajectory model based on the windrose approach of the Harwell Trajectory Model developed at Harwell Laboratory, UK (Derwent, Dollard & Metcalfe, 1988). In Ecosense, WTM is used to estimate the concentration and deposition of acid species on a European wide scale (ExternE, 1998). *The ExternE Project Ecosense Model – Exposure Response Functions for direct effects of sulphur*

	dioxide on crops (Exteme Programme, 1998)
	Emission Direct Contribution to Climate Change – Damage Modelling for the IPCC undertaken by Bruce et al., 1996 reported a range of damages from $5-$125 per tonne of carbon emitted in 1995. IPCC was unable to endorse any particular range or figure.
4.4 VOCs; NITRIC OXIDE; NITROGEN DIOXIDE	*Since troposheric ozone and photochemical oxidants are not primary pollutants there is no method available to specify the contribution emissions may have. Inventories of the precursors a may be compiled by and thresholds in countries have been established from tests on animals and accumulating evidence of damages to health and the environment, particularly crops.* *The ExternE Project Ecosense Model – Exposure Response Functions for direct effects of ozone on ozone-sensitive crops (European Commission, 1998).*
4.5 HALOCARBONS	*All are potent greenhouse gases and those that contain chlorine and bromine atoms have the ability to destroy stratospheric ozone. Baselines estimates of skin cancer (non-melanoma (NMSC) and malignant melanoma (MSC)) cases and deaths from are subtracted from the extra number expected as a consequence of stratospheric ozone depletion. The total number of incidences has been calculated for the Netherlands and Australia according to three scenarios: the IPCC IS92 scenario that shows large stratospheric ozone reductions in the coming decades; the London Amendments, and the Copenhagen Amendments to the Montreal Protocol. For example in the Netherlands, using a 1990 population scenario, the excess rate of NMSC increases from about 1 per 100,000 in 1990 to ~15 per 100,000 in 2050. For London and Copenhagen Amendments to the phasing out of ozone-depletors, the excess increases up to ~11 and 7 cases per 100,000 by the year 2050 (Martens, 1998).*
5 SOCIETY	
5.1 EMPLOYMENT; COMMUNITY ENHANCEMENT;	*The use of local multiplier effects can be used to assess the spread of economic influx in a region beyond those who are directly employed. Such positives can be significant especially as more community residents become associated with the activity and move to higher skill levels. Some negatives are also possible. These will vary with the degree of development already present. Areas that require attention include the shift of employment from traditional to non-traditional labour: destablising the purchasing power of the locals by paying higher prices or consuming a large proportion of locally needed resources; encouraging migration into a region with a subsequent strain on local services and resources; and the probability that the activity may cease (depleted reserves) bringing a bust to a now dependent economy (Jones et al., 1996).*
5.2 PUBLIC OUTRAGE; ETHICS	*The Negative Publicity Accounting Method is a risk-based approach that identifies a potential range of future share values and assigns a probability to each can be used to calculate a Risk Assessed Value (RAV) associated with public outrage (Holgate et al., 1997). The issues that attract attention are inherently unpredictable. However, by identifying those issues that the public are concerned about in Govemmental surveys (Department of the Environment, Transport and the Regions, 1998; Scottish Office, 1991) it is possible to identify certain facets of an event or issue that is likely to bring it to the media's attention. Identifying what it is that individuals are most concerned about can also be achieved by reviewing the characteristics of the most successful ethical funds or of those companies that perform well on the DowJones Sustainability Index. Corporate sustainability is an investable concept and it has been identified since the initiation of the index that sustainable companies not only manage the standard economic factors affecting their businesses but the environmental and social factors as well. There is mounting evidence that their financial performance is superior to that of companies that do not adequately, correctly and optimally manage these important factors (DowJones & Company, 2000).* *Environmental management has the potential to play a pivotal role in the financial performance of the firm. Many individuals suggest that profitability is hurt by the higher production costs of environmental management initiatives, while others cite anecdotal evidence of increased profitability. A theoretical model is proposed that links strong environmental management to improved perceived future financial performance, as measured by stock market performance. The linkage to firm performance is tested empirically using financial event methodology and archival data of firm-level environmental and financial performance. Significant positive returns were measured for strong environmental management as indicated by environmental performance awards and significant negative returns were measured for weak environmental management as indicated by environmental crises. The implicit financial market valuation of these was also estimated (Klassen et al., 1996).*

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Annex 2

"LOOK-UP TABLES" FOR ENVIRONMENTAL DAMAGE COSTS

Environmental Aspects	***Measurable Values***	***Abstracts of Environmental Valuation Studies***	***Valuation Study Location (High Income Countries Only)***
1 SOLID MATERIALS			
1.1 PRESENCE			
Visual Eyesore / Development	Property Values; Tourism; Species Loss/Gain; Fishery Catch	**1.1.1. David M. Dornbusch & Company, Applied Economic Systems, and Abt Associates, Impacts of Outer Continental Shelf (OCS) Development on Recreation and Tourism. Volumes 1,2 and 3, Prepared for Minerals Management Service, U.S. Department of the Interior contract number 14-12-0001-30166, Los Angeles, California, 1987.** This report presents estimates of the decline in consumer spending and consumer surplus associated with case studies in which offshore oil platforms are constructed and brought into operation off the California coast. This study estimated losses in value due to the temporary displacement of activities from a beach and construction noises that are incompatible with beach enjoyment, due to construction and operations of 3 oil rigs in the Eastern Santa Barbara Channel area and 2 oil rigs in the Northern Santa Barbara County area. Given specific assumptions regarding the size of the pipeline corridor, duration and timing of construction, etc., the study yielded the following estimate for construction and operation impacts: a decline in consumer surplus of \$69,000 and a decline in spending of \$186,000 for Eastern Santa Barbara, construction effects were deemed to be insignificant for Northern Santa Barbara County area as were spending changes. Impacts from oil rig operation impacts, which for this scenario were assumed to involve only the negative visual impacts of offshore oil rigs on beach recreation were estimated as follows: operation of the Eastern Channel oil rigs would lead to a \$1,430,000 decline in spending and \$517,000 in lost consumer surplus; The two rigs in Northern Santa Barbara County would cause an estimated \$12,000 in lost consumer surplus and a \$63,000 decrease in spending. The estimates are determined in a three step process using a "gravity model" to determine the number of visits to a site, a travel cost model, and an input output model. The study estimates combined consumer surplus losses from the construction and operation of the rigs of \$586,000 (-2.3%) and a decline in consumer spending of \$1,616,000 (-1.0%) (all values assumed to be in 1982 dollars).	USA
		1.1.2. Wilman, E.A., "Hedonic Prices and Beach Recreational Values.", Greenwich, CT: JAI Press 1981, The primary focus of this study was to present a mathematical and microeconomic basis for a hedonic model to estimate the effect of beach quality on rental rates for homes. The example used was beach homes rented out in 15 towns in Cape Cod, Massachusetts. In this region, water and beach pollution from oil spillage, tanker traffic and the construction of pipelines has increased in recent years. Data (n=196) on vacation home rental rates was obtained from realtors in the study site towns. Attributes of beaches near these homes were measured using information obtained from an inventory conducted by the Massachusetts Coastal Zone Program (1977). A demand-supply model estimated found the expected decrease in the monthly rental value of a home due to the presence of debris on a nearby beach was \$193.83. This would result in an overall seasonal loss to property owners of between \$6,000 to \$8,000 for beach houses in the Wellfleet area and \$8,000 to \$12,000 for homes in the Falmouth area. (Values in 1977 U.S. dollars) The Office of Ocean Management, National Oceanic and Atmospheric Administration, U.S. Department of Commerce supported this research.	USA
	Loss of Recreation	**1.2.3. Duffield, J., "Exxon Valdez - Lost Recreation Use" in Natural Resource Damages: Law & Economics, edited by K. Ward and J. Duffield., Natural Resource Damages: Law & Economics, edited by K. Ward and J. Duffield. New York: Wiley and Sons, 1992.**, The	USA

		study was a benefits transfer (secondary study based on existing data and literature). No primary survey efforts were undertaken. The unit values were based on TCM and CVM estimates in the "Southcentral Alaska Sport Fishing Economic Study" by Jones & Stokes Associates, Inc. 1987, and reductions in fishing use in 1989 were based on data collected by the Alaska Department of Game and Fish. The Jones & Stokes CVM study used to estimate nonresident values had a sample size of almost 5,000. Mean willingness to pay per user day based on the travel cost model estimated in the Jones and Stokes 1987 study was $213.57 for residents, $150.80 for nonresidents, and $204.24 when residents and nonresidents were combined. The mean estimated in this study for nonresidents from the contingent valuation method was $315.00, the truncated mean (the prefered estimate of the author) for nonresidents was $260.18, and the median for nonresidents was $204.09 (resident and combined values are not estimated). Being more conservative, and incorporating both resident and nonresident recreational anglers, the travel cost model estimate was used to calculate aggregate damages of $19.7 million for 1989. Using the truncated mean CVM estimate for nonresidents and applying it to residents and nonresidents resulted in estimated damages of $43.1 million for 1989. All values in 1987 US dollars.	
		1.2.4. Economic Analysis Inc., and Applied Science Associates Inc., "Measuring Damages to Coastal and Marine Natural Resources: Concepts and Data Relevant for CERCLA Type A Damage Assessments.", U.S. Department of the Interior, Washington, D.C., 1987., The study reports values per beach day, per visitor for national and other public beach in the Virginian province. These values are presented for each month. As well, "damage coefficients" are reported, which are defined as the lost value per beach day per meter of beach for a beach closed because of an oil or chemical spill. Two other tables in this study (not shown) report damage coefficients for beaches in ten marine provinces. As well, net value estimates of a beach visit are presented for nine empirical studies. Based on these estimates, the average lost value per visit was calculated to be $6.16. The baseline was the current condition of coastal and marine waters along beaches, or used for fishing, seal or waterfowl hunting and observing. The magnitude of change was marine waters affected by a discharge of oil or release of a hazardous substance. This discharge would cause the closure of a beach or result in the death of fish, waterfowl, or seals.	**USA**

		1.2.5. Bergstrom, J.C., J.R. Stoll, J.R. Titre, and V.L. Wright, "Economic Value of Wetlands-Based Recreation.", Ecological Economics 2, 129-147., 1990. A contingent valuation study was done to estimate the recreational value of Louisiana wetlands. The survey participants were recreational users of the wetlands. Uses included waterfowl hunting, freshwater fishing, saltwater fishing, recreational shrimping, and recreational crabbing. Passive uses may have been included indirectly, but were not directly measured. The survey asked participants to value wetlands protection under conditions of bag/catch limit conditions of 100%, 50%, and 25% of the current levels. An extensive "use" survey was conducted on site to establish the sampling frame for a large-sample mail-out survey from May, 1986 to January, 1987. A total of 3,842 questionnaires were mailed out using the Dillman method (1978) and there was a 55.2 percent response rate. The annual gross economic value of wetlands-based recreation was estimated at $145.236 million. The gross economic value is the sum of consumer surplus and expenditures made by recreationists. The study results indicated that the economic value of outdoor recreation functions of wetlands may be substantial. The study was funded by the U.S. Army Corps of Engineers through the Waterways Experiment Stations in co-operation with the New Orleans District. Annual Economic Value of Wetlands-based Recreation, Louisana Wetlands Study Area, (1986-87 U.S. dollars): Gross Economic Value (Consumer Surplus + Expenditure): $1,911.00 (Value Per User); $110.03 (Value per Hectare); $44.69 Value Per Acre; $145.236 million (Total). *Values per ha or acre must be interpreted with caution. They represent average values, not marginal values. Very small changes in wetlands should be valued using marginal values. In addition, a constant value per ha or acre implies that all wetlands area ha or acres are equally productive when, in fact, they are not. A loss of half of a wetland ecosystem may lead to a near total loss of recreational values or a minimal loss of recreational values, depending on environmental factors.*	USA
1.2 TURBIDITY	Habitat Loss or Degradation	**1.2.1. Holmes, T.P., The Offsite Impact of Soil Erosion on the Water Treatment Industry., Land Economics 64, no. 4, 356-366., 1988.** This study estimates that turbidity mitigation measures cost the water treatment industry between $4.40 and $82.34 per million gallons of water treated (1984 US dollars). In addition, the study estimates that, on average, "sediment discharges to surface water supplies induce treatment costs of $17.11 per thousand tons discharged." The 99% confidence interval for this per-unit estimate of damages is $10.84 to $27.95 per thousand tons of sediment discharged. This study uses two types of models to estimate the increase in water production costs associated with treatment to address sedimentation: (1) A "standard firm model," which involves estimation of a cost function for water treatment, and (2) A "hedonic cost function" model, which has a Cobb-Douglas [multiplicative] functional form. The effect of using the hedonic cost function model is that (a) the marginal effect of water quality on treatment cost depends upon the level of output [of finished water] and input prices, and (b) the relationship between treatment cost and input water quality is nonlinear. The damage estimates produced by the 2 models employed overlap significantly. In terms of nation-wide annual damages [costs] imposed on the water treatment industry as a result of sedimentation, the intersection of the two set of damage estimates [from the 2 models used] has a lower bound of $458 million per year and an upper bound of $661 million per year.	USA
		There were no other studies identified. Consequently the damage caused by turbid waters is considered non-quantifiable.	-
1.3 HEAVY METALS	Species Loss; Human Health	*There were no relevant studies identified. Consequently the damage caused by uptake of heavy metals from digested tainted seawater fish is considered non-quantifiable. The only related study that addresses heavy metal contamination values the availability of safe fishing areas.*	-
		1.3.1. Krieger, D.J., "The Economic Value of Environmental Risk Information: Theory and Application to the Michigan Sport Fishery", Dissertation, Michigan State University, 1994. This study uses a contingent valuation survey of 1991 Michigan fishing license holders to elicit willingness to pay for information on the testing of fishing sites for chemical contamination in public health advisory programs. Fishing sites on the Great Lakes may be contaminated with mercury, polychlorinated biphenyl (PCB), dichloro diphenyl	USA

		trichloroethane (DDT), dieldren, toxaphene, and chlordanes. The changes examined included the testing of more sites for chemical contamination of fish and the listing of safe fishing sites. The study found that anglers are willing to pay for a listing of safe sites and additional testing of sites for chemical contamination. For example, anglers are willing to pay $2.82 to $6.50 in increased license fees for information on 100 test sites (1991 U.S. dollars). The Michigan Sea Grant College Program provided support for this study.	
1.4 SEDIMENTATION	Species Loss	*There were no relevant studies identified. Consequently the damage caused by smothering of ecosystems is considered non-quantifiable.*	-
1.5 EXPOSURE TO LOW LEVELS OF RADIATION	Human Health	*There were no relevant studies identified. Consequently the damage caused by seabed disturbance is considered non-quantifiable.*	-
1.6 SEABED DISTURBANCE	Species Loss; Habitat Loss or Degradation	*There were no relevant studies identified. Consequently the damage caused by seabed disturbance is considered non-quantifiable.*	-
2 ENERGY			
2.1 DISTURBANCE	Property Values; Tourism; Species Loss and/or Decline; Fishery Catch Reduction	See 1.1	-
2.2 NOISE IN AIR	Species Loss and/or Decline; Public Complaints	**2.2.1. Kriström, B., "Spike Models in Contingent Valuation", American Journal of Agricultural Economics 79, no. 3, 1013-1023 , 1997.** This study investigated the suitability of including zero willingness to pay (WTP) bids in value estimation using two contingent valuation studies. The inclusion of zero bids creates a 'spike' at the origin when graphing WTP bids hence this procedure has been named spike modelling. The first study elicited WTP for re-routing passenger ferry traffic along the Stockholm archipelago in Sweden, and the second study elicited WTP for a reduction in air traffic at the Bromma airport. For the ferry study, 1,000 individuals living or owning property along ferry routes were surveyed, and for the air traffic study, 1,000 individuals living in the flight corridor were surveyed. Estimated median WTP for both studies was zero. Mean WTP for reduced air traffic also estimated as zero. Mean WTP to re-route ferry traffic was 1,500 Swedish krona ($200 U.S. dollars). The study recommended including zero WTP bids when estimating values in contingent valuation applications, and to construct the scenario to allow for both "winners" and "losers."	**Sweden**
		There were no other studies identified. The majority of studies in this area assess an individual's annual mean WTP for a reduction in negative socio-physical impacts occurring from increased tourism in an area	
2.3 NOISE IN WATER	Species Loss and/or Decline	**2.3.1. Hageman, Ronda, Valuing Marine Mammal Populations: Benefit Valuations in a Multi-species Ecosystem., National Marine Fisheries Service, Southwest Fisheries Centre, La Jolla, California, 1985, pp. 88., 1985.** The study used a contingent valuation survey with a payment card to elicit respondents' willingness to pay to prevent a decline in the present population of certain sea mammals from their current (1984) levels to historically low levels associated with the time when hunting of the animals was allowed. With an original sample size of 210, estimated mean WTP for the species, after the identification and removal of outlying responses, were as follows: Blue and Gray whales: $23.95 Bottlenose Dolphins: $17.73 California Sea Otters: $20.75 Northern Elephant Seals: $18.29 An analysis of the WTP responses found that generally 9% to 12% of the mean value could be attributed to non-consumptive use, 22% to option value, and 65% to 72% to existence values.	**USA**
		2.3.2. Samples, Karl C., John A. Dixon and Marcia M. Gowen., Information Disclosure and Endangered Species Valuation., Land Economics Vol 62, no. 3, 306-312., 1986. The main purpose of this study is to examine the effects of providing information to participants in contingent valuation (CV) surveys. The study, which was performed in Hawaii, asked 228 respondents their willingness to pay (WTP) for the preservation of humpback whales. Half the participants were then	**USA**

		shown a video about humpback whales (this was the experimental group, where the sample size was 115) while the other half were shown a video on an unrelated topic (this was the control group and the sample size was 113). After the videos the participants were again asked their WTP. The results showed that before information was given the mean WTP values were: $42.84 for the experimental group, and $36.33 for the control group. After information was given the mean WTP values were: $57.06 for the experimental group, and $43.71 for the control group. The authors note that these WTP values are representative of the sample. Because the purpose of this study was to compare values before and after information was given, the sample is not representative of the population as a whole. Values are in U.S. dollars. The year of the currency and the survey are not given.	
		There were no studies identified that quantify in monetary terms the impact of noise on marine fauna from offshore oil and gas exploration.	
2.4 UNDERWATER EXPLOSIVES	Species Loss and/or Decline	See 2.3	-
2.5 VIBRATION	Species Loss and/or Decline	*There were no relevant studies identified. Consequently the damage caused by vibration is considered non-quantifiable*	-
3 LIQUID DISCHARGES			
3.1 OIL DISCHARGE	Species Loss and/or Decline; Habitat Loss or Degradation; Human Health; Public Complaints	**3.1.1.Carson, R. T., R.C. Mitchell, W.M. Hanemann, R. J. Kopp, S. Presser and P.A. Ruud, A Contingent Valuation Study of Lost Passive Use Values Resulting From the Exxon Valdez Oil Spill., Report to the Attorney General of the State of Alaska, Reprinted by Natural Resource Damage Assessment, Inc., 1992.** , The study presents a scenario in which respondents' willingness to pay is elicited for a program that would avoid another oil spill like that of the Exxon Valdez. The passive use values were related to injuries realised by birds, mammals, fish, and oiled shorelines (endangered species were not referenced). Median household WTP for program to prevent future injuries to natural resources similar to those caused by the Exxon Valdez oil spill is $30.91 with a 95% confidence interval of $26.85-$35.59 when a Weibull distribution is assumed (the Weibull was the preferred distribution but other distributional assumptions were examined and are presented in Table 1). Total passive value for U.S. based on the Weibull median estimate and the number of English speaking households in the U.S. is $2.8 billion (all values are in 1991 US dollars). All values are measured on a per household basis in 1991 US dollars. These values can be found in Table 5.8 of the original study. Multiplying the median Weibull estimate by the number of English speaking households in the U.S. provides the study's value of $2.8 billion (1991 US dollars) as being the lost passive use value associated with the Exxon Valdez spill	USA
		3.1.2. Grigalunas, T.A., J.J. Opaluch, D. French, and M. Reed, Measuring Damages to Marine Natural Resources from Pollution Incidents under CERCLA: Applications of an Integrated Ocean Systems/Economic Model., Marine Resources Economics 5, 1-21. , 1988. This study reports the results of a sample run of the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME). The model uses an integrated ocean system/economic model to simulate the biological effects of a spill and measure the resulting economic damages. Specifically the economic damages to fisheries are calculated based on allocating the estimated lost stock between commercial and recreational fisheries. The economic value of the commercial fishery is based on a database of avaerage prices while the recreational value is based on an average of the marginal value per fish estimated in a series of studies. The economic value of the lost waterfowl is made using an average of marginal values for waterfowl from available studies. The value for seabirds is based on the marginal change in visitor days associated with the change in bird population for a wildlife refuge and a value for a unit day of bird watching. The value associated with beach closures is similarly estimated based on historical beach use data, an estimate of the length of closure and a unit value for lost trips. Damages to commercial and recreational finfish, due to a 100-metric-ton spill of diesel fuel oil during the summer season, as estimated by the model are as follows: Anadromous fish $71.82 Planktivorous fish $4,431.65 Piscivorous fish $12,584.98 Demersal fish $13,303.25 Semi-demersal	USA

		fish $11,345.97 Total for fish $41,737.00 Equivalent damage to Commercial invertebrates: Molluscs $4153.40 Decapods $62.77 Squid $38.54 Total for commercial invertebrates $4254.00 Losses for Birds and Mammals: fur seals $0.00 Sea birds $295.25 Waterfowl $763.48 Total birds and mammals $1,058 Additional estimates are for a range of spill sizes in the summer season in the Virginian province by location (marine or estuarine). These values range from $2,491 (estuarine) and $329 (marine) for a 5 metric ton spill to $426,668 (estuarine) and $312,377 (marine) for a 1,000 metric ton spill. Values for a 100 Metric ton spill vary by location and season from a low of $1,216 in the Arctic province in the winter to a high of $373,341 for a spill in the California province in the spring. Damages for the 100 metic ton baseline spill (summertime, estuarine in the Virginia province) would have varying associated damages depending on the shoreline type. The associated damage estimates are as follows by type of shoreline: rock - $447,018 cobble - $114,759 mud flat - $11,466 salt marsh - $79,723 sand - $15,295 For 100 metric ton summertime, estuarine spills in the Virginia province the damages would also vary depending on the nature of the petroleum product ranging from a low of $31,484 for a spill of kerosene to a high of $179,378 for No.2 fuel oil (diesel fuel). Damages are also presented for 20 and 100 metric ton summertime estuarine spills in the Virginia province of alternative chemicals (Pentachophenol, Aldrin, Benzene, Xylene, Toluene) with the lowest damages associated with Xylene ($4,096 for a 20 metric ton spill and $23,950 for a 100 metric ton spill) and the highest damages associated with Aldrin ($427,803 for a 20 metric ton spill and $968,474 for a 100 metric ton spill). All values in 1986 US dollars. Further Species Damage Assessment Estimations are available.	
		3.1.3. Cohen, M. A., "The Costs and Benefits of Oil Spill Prevention and Enforcement.", Journal of Environmental Economics and Management 13, 167-188. , 1986., The baseline is the condition of a waterway before an oil spill. This condition relates to the health/morbidity of marine plants, animals, birds and fish that rely on this waterway for subsistence. The magnitude of change is the condition of a waterway after an oil spill. This condition relates to damage done including the number of marine animals and plants destroyed by the spill. Average Damage valuations are taken from case studies and include the Amoco Cadiz $2.14-$4.24/ gallon of oil; STC-101 $4.14; Zoe Colocotroni $9.06; and, Standard Oil $1.13.	**USA**
		3.1.4. National Oceanic and Atmospheric Administration, Assessing the Social Costs of Oil Spills: The AMOCO CADIZ Case Study., National Oceanic and Atmospheric Administration, U.S. Department of Commerce, July 1983. The Brittany coast is the second most popular summer vacation area in France, with marine-related tourism, oyster culturing, lobster harvesting and storage, and fisheries being major economic activities in Brittany. Approximately 216 thousand tons (metric) of light Arabian crude oil and 4 thousand tons of bunker fuel were spilled by the Amoco Cadiz on March 16, 1978. The affected area is characterised by rocky headlands, crenulated bays, sandy beaches, and barrier islands; it is similar to the coasts of Maine and southern Alaska. It is highly productive biologically. Net social cost to the open-seas fisheries of Brittany (covering the Grest, Morlaix, and Paimquol quarters) from March 1978 to December 1979 was estimated, in terms of 1978 French francs, at 19.81 million. This total includes 1.71 million francs for finfish, 8.01 million francs for crustaceans, 10.13 million francs for molluscs, and a benefit of 0.04 million in reduced costs for fishing effort from Paimpol. Gains and losses for the March 1978 to December 1979 period were derived by discounting the gains and losses for the months subsequent to March 1978 using a real discount rate of 3%. Uncertainties in the analysis include the quality of catch and price data, and of individual boat operations data, the period of loss resulting from the spill, and that no attempt was made to model the demand side of the fisheries market (considered a minor limitation of the analysis). Total costs for the oyster-culturing industry were estimated at 106.7 million 1978 French francs. This total cost estimate was distributed as follows: wholesale value of destroyed oyster and mussel stocks, 37.0 million francs; costs of transferring oysters away from polluted zone and eventual return, 1.2 million francs; costs of cleanup and restoration of buildings and equipment above the level of cleanup provided by the French government, 5.3 million francs; costs of cleanup and restoration of the lands leased by the oyster producers above the level of cleanup provided by the French government, 3.5 million francs; value of the loss of expected production of oysters (those	**France**

		remaining) over the years 1978-1981, 59.7 million francs. Uncertainties in the estimates include (1) the assumption of no productions losses beyond 1981, which may have been too optimistic since sediments were still contaminated with hydrocarbons in 1981, and (2) the assumption of no increases in production over the pre-spill period levels in the absence of the spill.	
		3.1.5. Rowe, R.D., W.D. Shaw, and W. Schulze, "Nestucca Oil Spill", In Natural Resource Damages, edited by K. Ward and J. Duffield., New York: Wiley and Sons, 1992. The Nestucca oil spill occurred in Gray's Harbor and subsequently affected the WA and BC coastline. 231,000 gallons of oil were spilled. Injuries included: oiled beaches; 50,000 dead seabirds; effects on fisheries; marine plants; other aquatic life. The injuries lasted for over a month. A 1990-91 payment card contingent valuation (CV) survey of Washington and British Columbia residents was used to estimated the WTP for oil spill prevention. The study estimates the following values. All values are mean household WTP over five years to prevent spills. Washington values, in 1991 U.S. dollars: for routine very small spills each year $25; for several small spills in 5 years $40-$50; for one moderate spill each five years $65-$95; for a large spill once in a lifetime $110-$160. British Columbia values, in 1991 Canadian dollars: for very small $20-$40; for small $35-$65; for a moderate spill $55-$105; for a large spill $80-$170. The study also discusses ways to correct several CV biases, including: part-whole embedding, temporal embedding, information bias, and non-participation bias.	**USA & Canada**
		3.1.6. Bockstael, N.E., W.M. Hannemann, and C.L. Kling, "Estimating the Value of Water Quality Improvements in a Recreational Demand Framework.", Water Resources Research 23, no. 5, 951-960. , 1975, For the study, a series of discrete choice and hedonic travel cost models were estimated. The data used for analysis was collected by the Environmental Protection Agency (EPA) in 1975 on trips to Boston-area beaches, and measures of water quality at those beaches. These beaches were polluted with faecal coliform, oil; are turbid and have low levels of oxygen. Table 1: Average Compensating Variation Estimates of Specific Pollutant Reductions at Boston Area Beaches. 1.Value per choice occasion (2) value per season: 10% reduction in oil at all sites $0.05, $0.96; 30% reduction in oil at all sites $0.20, $4.66; 10% chemical oxygen demand reduction at all sites $0.12, $2.65; 30% chemical oxygen demand reduction at all sites $0.29, $7.15; 10% fecal coliform reduction at all sites $0.02, $0.19; 30% fecal coliform reduction at all sites $0.12, $2.85; 30% reduction in oil, turbidity, COD, and fecal coliform at all sites $0.50, $12.04; 30% reduction in oil, turbidity, COD, and fecal coliform at downtown Bostonsites $0.27; $6.13. Notes: Values are all in 1974 US dollars.	**USA**
		3.1.7 Kahneman, D., and I. Ritor, "Determinants of Stated Willingness to Pay for Public Goods: A Study in the Headline Method", Journal of Risk and Uncertainty 9, no. 1, 5-38 , 1994 This study estimated willingness to pay (WTP) for public goods. Environmental issues were evaluated by 1,441 visitors to the *Exploratorium* (a science museum in San Francisco) during 1991 using a self-administered, on-site questionnaire. The issues considered included several animal species, plant species, ecological damage, public health, and historic buildings. WTP values ranged from $3.60 to $16.28 for animal species, from $2.24 to $12.03 for plant species, from $5.44 to $23.96 for ecological habitat, from $5.67 to $8.40 for other public goods, and from $10.96 to $17.42 for public health (1991 U.S. Dollars). This study was funded by a Chevron grant for risk assessment research. Mean Willingness to Pay (WTP) for Animal Species (1991 U.S. Dollars): American Elk $7.69; Wildlife $13.30; Black-footed Ferret $9.55; Birds $8.91; Elephants $16.28; Spotted Owl $14.55; Marine Life $13.08; Kangaroo Rats $6.33; Florida Panther $6.81; Falcon Shell $11.21; Dolphins $12.57; Australian Mammals $8.42; Coastal Reptiles $3.60. Mean Willingness to Pay (WTP) for Plant Species and Ecological Damage (1991 U.S. Dollars): Mushroom $3.63; Pine Disease $5.76; Spanish Moss $2.24; Pine Trees $9.79; Coral Reefs $12.03; Wetlands	**USA**

		$11.49; Carbon Dioxide in the Third World $5.44; Carbon Dioxide (Oil Burning) $19.88; Automobile Pollution $18.57; Burning Rain Forest $23.96; Visibility in Parks $9.56; Toxic Waste Dumps $20.67; Shrinking Rain Forest $16.93; Toxic Spills $9.98; and, Solid Waste $15.64. WTP in the form of a voluntary contribution on a state income tax form. For habitats WTP is for a specific intervention to deal with each problem.	
3.2 BALLAST WATER	Species Loss and/or Decline; Habitat Loss or Degradation	*There were no relevant studies identified. Consequently the damage caused by ballast water is considered non-quantifiable*	-
3.3 CHEMICALS	Species Loss and/or Decline; Habitat Loss or Degradation; Water Quality Decline; Human Health; Public Complaints	**3.3.1 Kawabe, M. and T. Oka, "Benefit from Improvement of Organic Contamination of Tokyo Bay", Marine Pollution Bulletin 32, no. 11, 788-793, 1996.** This study estimated the benefits of improving water quality in Tokyo Bay, Japan, using two methodologies: the travel cost method (TCM) and contingent valuation, (CV). Bay water has been contaminated by many industrial facilities which discharge into rivers that drain into the bay. The bay shores are used for recreational activities like bathing, surfing and shore fishing. Data for the study was collected from several sources. The main source was a large-scale survey of 1000 people, which had a 28.9 percent response rate. Several government sources were used for data for the travel cost model. There were three TCM models estimated based on the type of recreational activity. No formal model was presented for CV. The TCM was used to estimate the consumer surplus associated with a 65 percent decrease in nitrogen runoff. Responses to a contingent valuation question were used to estimate willingness to pay to keep the water in Tokyo Bay from becoming reddish-brown in colour. The total economic benefit for water quality improvements estimated by the TCM was 458.3 billion Japanese yen per year (4.3 billion U.S. dollars), compared to 1,285 billion Japanese yen per year (12 billion U.S. dollars) estimated by the CVM (1993 Japanese Yen). The estimated cost for implementing the 65 percent rate of reduction in nitrogen runoff is 49 billion yen per year (0.5 U.S. dollars), or 10.7 percent of the benefits estimated by the TCM.	**Japan**
	Water Quality Decline	**3.3.2 Collins, A.R. and S. Steinback, "Rural Household Response to Water Contamination in West Virginia", Water Resources Bulletin 29, no. 2, 199-209., 1993.** This study uses averting expenditures to estimate willingness to pay of rural households in West Virginia for a reduction in water contamination. Domestic water supply systems of these households may be contaminated by bacteria (faecal coliform organisms), minerals (iron, magnesium, sodium, sulphur, pH, manganese and hardness) and organic compounds (phenols, toluene, oil, petroleum). A combined mail and telephone survey was administered in 1990 to a sample of households with water contamination. These households incurred costs for the following averting behaviour categories: boiling water, delivered bottled water, hauling water, installing a treatment system, purchasing bottled water, correcting the source of the contamination, establishing a new water source, and cleaning or repairing the water system. Total willingness to pay is the sum of household labour costs and monetary costs. Annual household willingness to pay for a reduction in water contamination ranges from $309 to $1,090, depending on the contaminant and the averting behaviour. Annual household WTP to reduce contamination of drinking water by heavy metals was $357 (US$1990). The West Virginia University Agricultural Experiment Station and the U.S. Geological Survey provided support for this research.	**USA**
		3.3.3. Cho, Y., "Willingness to Pay for Drinking Water Quality Improvements: A Contingent Valuation Study for Southwestern Minnesota", Dissertation, University of Minnesota, 1996. This study uses the contingent valuation method to elicit 640 Minnesota residents' willingness to pay (WTP) for reduced levels of iron, sulphate, hardness and copper in their community drinking water. Respondents were asked their willingness to pay to reduce current levels to below the U.S. Environmental Protection Agency's established standard levels. Annual mean WTP ranges from $32.16 to $43.56 to reduce iron levels, from $25.44 to $36.00 to reduce sulphate levels, from $33.36 to $47.88 to reduce hardness levels, and from $25.08 to $35.88 to reduce copper levels (1995 U.S. dollars). When annualised, WTP values exceed the	**USA**

		average annual household costs of implementing water treatment facilities in communities with 500 or more drinking water users.	
		3.3.4. Harris, B.S., "Contingent Valuation of Water Pollution Control", Journal of Environmental Management 19, no. 3, 199-208 , 1984. This study used the contingent valuation method to estimate willingness to pay (WTP) for water quality improvements in the Waikato Basin on the North Island of New Zealand. Discharge from various industries, such as pulp and paper mills and meat works, as well as agricultural run-off, has polluted rivers in the basin. A professional market research firm administered the survey to a sample drawn from the four main centres of the Waikato Basin. Resident annual WTP to improve water quality in the Waikato Basin was estimated to be $3.7 million, individual WTP was estimated as $16 per person. Visitor WTP was $1.6 million and national WTP was $2.85 million. Adding these values to the $4 million market benefits of the water quality improvements in the Waikato Basin results in a total value of $12 million per year. In comparison, the costs of achieving and maintaining the current level of Waikato Basin water quality over the past 20 years, in present day values, are about $100 million.	**New Zealand**
		3.3.5. McClelland, G.H., W.D. Schulze, J.K. Lazo, D.M. Waldman, J.K. Doyle, S.R. Elliot, and J.R. Irwin, Methods for Measuring Non-Use Values: A Contingent Valuation Study of Groundwater Cleanup., Center for Economic Analysis, University of Colorado, Boulder, CO, October 1992. The study uses a data from a contingent valuation payment-card survey to develop estimates of mean household willingness-to-pay (WTP) for complete cleanup of groundwater contaminated from a leaking landfill, which had also resulted in a 40% shortage in domestic water supply, was $14.70 per month ($176.40 annually) and $11.58 per month ($138.96 annually) when adjusted for by the share of the value that is for the cleanup program. When the data is adjusted using a Box-Cox transformation to account for measurement error in the WTP combined with the shares reported for the amount of the WTP value that was for the program the monthly mean household WTP for the groundwater cleanup program is $7.01 ($84.12 annually). The study also estimates the mean nonuse values (sum of existence and bequest values) associated with the program. The untransformed mean nonuse value is $5.70 per month ($68.40 annually) while the Box-Cox adjusted value is $3.48 per month ($41.76 annually). All values are in 1991 US dollars.	**USA**
		3.3.6. Page, G.W., and H. Rabinowitz, "Groundwater Contamination: Its Effects on Property Values and Cities.", Journal of the American Planning Association 59, no. 4, 473-481 , 1993. This study summarised and analysed the findings of twelve case studies dealing with the effects of groundwater contamination on property values at former industrial sites. The study sites were located in three states: Wisconsin, California and Pennsylvania. A variety of toxic chemicals such as PCBs, petroleum from underground storage tanks and chromium leached into the ground at these sites. These chemicals degrade slowly, and are extremely expensive and difficult to clean-up. The study results indicate groundwater contamination has negatively impacted the value of industrial properties but has not impacted the value of residential properties. The reasons given were that liability risks for commercial property clean-up are great enough to affect property values. For residential sites, appraisers and brokers lack accountability and avoid discussing environmental issues with buyers. The study was funded by the Wisconsin legislature.	**USA**
		3.3.7. Boyle, K.J., Poe, G.L. and J.C. Bergstrom, "What Do We Know About Groundwater Values? Preliminary Implications from a Meta Analysis of Contingent Valuation Studies", American Journal of Agricultural Economics 76, 1055-1061, 1994. The importance of groundwater quality has led the U.S. Environmental Protection Agency to assess the benefits and costs of groundwater protection policies. A meta analysis is used to quantitatively review eight contingent-valuation studies on groundwater protection. These studies cover five states in which the groundwater quality is affected by nitrates, pesticides, and other contaminants. Willingness to pay for groundwater quality is examined as a function of groundwater contaminants, survey design, survey implementation, and estimation procedures. Willingness to pay ranges from $56 to $1,154 across the studies used in the meta analysis. The authors conclude that one limitation of the study is the	**USA**

.		inconsistent definition of groundwater contamination given across the studies included in the analysis. However, consistency in the estimated effects of core variables indicates that groundwater values are more than random noise.	
3.4 SEWAGE & CANTEEN WASTES	Habitat Loss or Degradation	*See 3.1.6; 3.3.1; 3.3.2*	-
3.5 OIL-BASED MUDS	Species Loss and/or Decline; Habitat Loss or Degradation; Water Quality Decline; Human Health; Public Complaints	*See 3.1 There were no studies identified that quantify in monetary terms the impact of OBMs on marine flora and fauna from offshore oil and gas exploration.*	-
3.6 SYNTHETIC-BASED MUDS	Species Loss and/or Decline; Habitat Loss or Degradation; Water Quality Decline; Human Health; Public Complaints	*See 3.3. There were no studies identified that quantify in monetary terms the impact of SBMs on marine flora and fauna from offshore oil and gas exploration.*	-
3.7 WATER-BASED MUDS	Species Loss and/or Decline; Habitat Loss or Degradation	*See 3.3. There were no studies identified that quantify in monetary terms the impact of WBMs on marine flora and fauna from offshore oil and gas exploration.*	-
3.8 HEATED WATER	Species Loss and/or Decline; Habitat Loss or Degradation	*There were no studies identified that quantify in monetary terms the impact of thermal pollution on marine flora and fauna from offshore oil and gas exploration.*	-
3.9 BRINES	Species Loss and/or Decline; Habitat Loss or Degradation	*There were no studies identified that quantify in monetary terms the impact of increasing salinity on marine flora and fauna from the discharge of brines during offshore oil and gas exploration.*	-
4 GASEOUS EMISSIONS			
4.1 CARBON DIOXIDE	Species Loss and/or Decline; Habitat Loss or Degradation; Crop Productivity; Water Quality Decline; Human Health; Property Values; Public Complaints; Refugee Crisis	**4.1.1 Spash, C.L., "Intergenerational Transfers and Long Term Environmental Damages: Compensation of Future Generations for Global Climate Change Due to the Greenhouse Effect", Dissertation, University of Wyoming , 1993.** This study used the contingent valuation method to measure willingness to pay (WTP) compensation to future generations for the greenhouse effect. A mail survey was administered to a sample drawn from the University of Stirling, and in-person interviews were conducted with individuals from the University of Wyoming and Glasgow. Respondents were asked to value five events potentially caused by the Greenhouse effect, including $33 billion worth of crop losses in the United States each year, flooding of 11 percent of Bangladesh affecting 8.5 million people, 50 million people in the arid areas of the Third World being forced off their land by persistent droughts, total melting of the West Antarctic ice sheet by 2092 causing an average sea level rise of 6 meters, and total submersion of the Maldives by 2092, forcing 177,000 people to lose their homes and be relocated. Responses to willingness to pay questions were compared for sub-samples of the data categorised by the respondents' beliefs about obligations to future generations, by respondents' beliefs about whether future generations have inviolable rights, by payment transfer mechanism used in the valuation question, and by geographic location of the sample. Annual WTP ranged from £2.19 in direct bequests by the Glasgow sample to compensate future generations for flooding of the Maldives to £188.90 in research and development costs by the Wyoming sample to compensate for crop losses in the United States. The currency year and year of survey administration were not provided in the study but the survey used an exchange rate of one U.S. dollar equal to 0.56 British pound. Annual Mean Household Willingness to Compensate Future Generations for the Greenhouse Effect, by Transfer Mechanism (British Pounds): ▪ Direct Bequests - Crop Loss in U.S. £42.10; Floods in Bangladesh £12.04; Third World Drought £16.45; Sea Level Rise £12.75; Flooding of Maldives £10.00. ▪ Research & Development - Crop Loss in U.S. £70.00; Floods in	USA

		Bangladesh £28.70; Third World Drought £32.72; Sea Level Rise £24.48; Flooding of Maldives £21.20. ▪ Capital Investment - Crop Loss in U.S. £66.00; Floods in Bangladesh £26.43; Third World Drought £28.06; Sea Level Rise £21.56; Flooding of Maldives £26.50.	
		See 3.1.7; 4.3.1;	-
4.2 CARBON MONOXIDE	Human Health	-	-
4.3 OXIDES OF NITROGEN	Species Loss and/or Decline; Habitat Loss or Degradation; Crop Productivity; Water Quality Decline; Human Health; Property Values; Public Complaints; Refugee Crisis	**4.3.1 Burtraw, D. and M. Toman, "The Benefits of Reduced Air Pollutants in the U.S. from Greenhouse Gas Mitigation Policies", Discussion Paper 98-01,Resources for the Future , 1997.** This study examined the economic impacts of greenhouse gas emission reductions in the United States. Ancillary benefits occur because policies aimed at reducing greenhouse gases may simultaneously result in reductions of conventional pollutants. Ancillary damages caused by the operation of a new coal steam plant (an identified source of greenhouse gas pollution) in New York state were estimated with a program that predicts the environmental and economic impacts of power plants (EXMOD). Damages ranged from -$0.02 to $2.92 per megawatt-hour, depending on the pollutant and the region of New York state affected (urban, suburban, or rural), particulates $0.29-$2.92, sulphur oxides without allowance cap and trading programme $0.98-$1.96, sulphur oxides with allowance cap and trading programme $0.01-$0.58, or nitrogen oxides $0.02-$2.79. The ancillary benefits of a one ton carbon reduction were also estimate with EXMOD and compared to seven other estimates, resulting in an ancillary benefits range of $2.64 to $78.85 per ton of carbon reduction (1992 U.S. dollars). The study attributes the disparity in values to a number of factors, including the differences in modelling criteria for pollutant emissions reductions, changes and developments in health epidemiology and valuation literature over the last few years, and the differences in sectoral and pollutant coverage in the studies. This study concludes that ancillary benefits should be considered by policy makers to accurately reflect net costs of greenhouse gas mitigation policies. This study was partially funded by the U.S. Environmental Protection Agency.	USA
		4.3.2 Farber, S. and A. Rambaldi, "Willingness to Pay for Air Quality: The Case of Outdoor Exercise", Contemporary Policy Issues 11, no. 4, 19-30, 1993. This study used the payment card contingent valuation method to estimate willingness to pay (WTP) for ozone concentrations that never exceed National Ambient Air Quality Standards (NAAQS) in East Baton Rouge, Louisiana. At the time of the study, the NAAQS ozone standard of 12 parts per hundred million was exceeded 14 days a year. Surveys were administered by mail to a sample of 1,386 individuals who regularly participated in outdoor exercise in the study area. Annual individual median WTP for all incidents of NAAQS exceedences ranged from $45 to $95, and for one exceedence from $3.21 to $25.39 (1991 U.S. dollars). Aggregate WTP was estimated to be between $12.4 and $20.6 million per year. Estimated values were found to be comparable to those from similar studies done in the Los Angeles, California area.	USA
		4.3.3 Brucato, P., J.C. Murdoch, and M.A. Thayer, "Urban Air Quality Improvements: a Comparison of Aggregate Health and Welfare Benefits to Hedonic Price Differentials", Journal of Environmental Management, vol. 30, no. 3, 265-279 , 1990. The San Francisco Bay Area Basin has had a long history of air pollution problems as a result of high ozone levels. This study evaluated the health and welfare effects resulting from a 10 percent reduction in ozone levels for single family residences in five counties in the San Francisco Bay Area Basin. Two approaches were considered, including a damage function approach and a hedonic equation approach. For the damage function approach, concentration-response relationships were used together with contingent valuation estimates of willingness to pay (WTP) for reduced acute and chronic health effects to value annual benefits of a 10 percent reduction in ozone levels. Reductions in plant and materials damage were also valued. The ozone concentration response functions, WTP estimates, and plant and materials damage data used were based on data from previous studies. Annual Willingness to Pay (WTP) estimates for a one day reduction in health	USA

		effects due to ozone reduction from previous studies (1984 US$): *Asthma Attacks: Low Estimate $9.00; Medium Estimate $25.00;* High Estimate *$41.00; Respiratory* Symptom Days – Cough: Medium Estimate *$4.00;* High Estimate $8.15; Respiratory Symptom Days – *Chest Discomfort:* Medium Estimate $8.00; High Estimate $8.88; Non-respiratory Symptom Days – Eye Irritation: Medium Estimate $5.00; High Estimate $10.85; Non-respiratory Symptom Days – Headaches: Medium Estimate $5.00; High Estimate $21.00; Restricted Activity Days – minor respiratory-related restricted activity day: Low Estimate $11.00; Medium Estimate $18.00; High Estimate $30.50; Restricted Activity Days – school loss days: Medium Estimate $16.00; Restricted Activity Days – bed disability days: Medium Estimate 32.80; Chronic Respiratory Disease: Low Estimate $12,590; Medium Estimate $21,830; High Estimate $32,730. (The annual WTP to avoid chronic respiratory disease was calculated by adding the direct medical costs (hospital, doctor, and drugs) to the cost of lost work due to illness to yield a cost of illness (COI) estimate. This COI estimate was multiplied by an adjustment factor to reflect pain and suffering. The final step was to covert to present value, using a discount rate of 3 percent). The best estimate of the present value of marginal benefits was $316 million, over a 30 year period (1984 U.S. dollars). For the second approach, a hedonic equation was specified and the price differential for a 10 percent reduction in ozone levels was calculated. Market sales data for 1978 and 1979 was used to estimate housing characteristics. The best estimate of the price differential aggregated over households affected by ozone levels in the San Francisco area was valued at $430 million over a 30-year period.	
4.4 SULPHUR DIOXIDE	Species Loss and/or Decline; Habitat Loss or Degradation; Crop Productivity; Water Quality Decline; *Human Health*	**4.4.1 Joyce, T.J., M. Grossman, and F. Goldman, "An Assessment of the Benefits of Air Pollution Control: The Case of Infant Health", Journal of Urban Economics 25, 32-51, 1989.** This study used a production function of infant health to estimate social willingness to pay (WTP) for reductions in sulphur dioxide levels that result in increased *neonatal survival rates. Although this study analysed a number of* different air pollutants, sulphur dioxide produced the most consistent and significant effects on neonatal mortality. The pollution data used in the study came from the U.S. Environmental Protection Agency's (EPA) Storage and Retrieval of Aerometric Data (SAROD). Social marginal WTP for a 10 percent reduction in sulphur dioxide concentrations ranged from $1 to $110 per year (1977 U.S. dollars), depending on the race of the sample and whether prenatal or neonatal care was used in the WTP calculation. The annual aggregate benefit of a 10 percent reduction in sulphur dioxide levels was estimated to be between $54 million and $1.09 billion. The U.S. EPA funded this research.	**USA**
		4.4.2 Minns, C. K. and J. R.M. Kelso, "Estimates of Existing and Potential Impact of Acidification on the Freshwater Fishery Resources and Their Use in Eastern Canada.", Water, Air, and Soil Pollution 31, 1079-1090., 1986. This study estimates the impact of acidification of freshwater fishery resources in eastern Canada. The study combines recreation fishing visitation and expenditure data from a 1980 Department of Fisheries and Oceans study with lake acidity data from Kelso et al (1986) to predict the effect of acidification on angler expenditures. Using 1980 acid deposition rates, the authors predicted that 1,870,000 angler days and $59.7 million in expenditures by those fishermen would be lost. This is based on a model that predicts the number of lakes too acid for fish to inhabit would increase from the current 14,000 lakes in eastern Canada to 65,000 lakes. The researchers noted the cost of emission control is expected to be high, so another alternative is amelioration of the acidification effects by chemical treating such as liming. Assuming the logistics of this was solved and there were no side effects, treatment of these 65,000 lakes could cost $75 million per year. If less acidic lakes were treated, with pH less than 6, the cost would be $172 million per year. (Values in 1980 Cdn. dollars)	**Canada**
		4.4.3 Burtraw, D., A. Krupnick, E. Mansur, D. Austin, and D. Farrell, "The Costs and Benefits of Reducing Acid Rain", Discussion Paper 97-31-REV, Resources for the Future, 1997. A cost-benefit analysis was performed to examine the effects of the 1990 Clean Air Act Amendments Title IV Allowance Trading System for reducing electric power plant emissions (acid rain, sulphur dioxide, nitrogen oxides, fine particulate matter (PM10)). Benefits, estimated using the National Acid Precipitation Assessment Program's Tracking and	**USA**

		Analysis Framework model, were compared to the costs of the program over the period of 1995 to 2030. Three areas were examined including health effects (days of morbidity effects (illnesses), cases of chronic disease, statistical lives lost to premature death), visibility (changes in residential and recreational visibility for five cities and two national parks), and recreational lake fishing (economic benefits from improved fishing caused by decreased acidification). Benefits in the form of reduced risk of premature death, improved health morbidity, and improved residential and recreational visibility were estimated. Estimated mortality benefits and costs were compared to values derived in other studies. This study found that benefits of the program exceed program costs, even when accounting for statistical uncertainties associated with modelled health effects and monetary values. State Health Benefits from Reduced Sulphur Dioxide Emissions in 2010 ranged from \$130.70 per capita - \$171.38 per capita. Health benefits are reduced risks of morbidity and mortality. Per Capita and Per Ton Benefits in 2010 for Reduction in Sulphur Dioxide and Nitrogen Oxides Emissions (1990 U.S. Dollars): Benefits per tonne of Sulphur dioxide: Morbidity \$193; Mortality \$3,102; Benefits per tonne of Nitrogen dioxide: Mortality \$463; Morbidity \$137. This study was funded by the National Acid Precipitation Assessment Program member agencies, including the U.S. Department of Energy, U.S. Environmental Protection Agency, and the National Oceanic and Atmospheric Administration.	
		4.4.4 Welle, P.G., "Potential Economic Impacts of Acid Deposition: A Contingent Valuation Study of Minnesota", Dissertation, University of Wisconsin-Madison, 1986. This study estimated the value of protecting lakes and streams in north-eastern Minnesota from the effects of acid deposition, (rain). Using a visual aide called an 'environmental quality ladder,' respondents were asked their willingness to pay to protect lakes from the progressively severe effects of acid rain, such as the loss of fish, water birds and the thinning of forests. These effects may start in the next few years with the severe effects taking longer. Acid deposition is caused by burning of fossil fuels, mainly from electric utilities in the U.S. and non-ferrous smelting in Canada. Sulphur and nitrogen oxides are the precursors. A mail survey was sent to a random sample of 1,000 adults drawn from a list of Minnesota drivers' licenses to elicit willingness to pay values. The mean total value of preventing severe and moderate effects of acid deposition in lakes and streams in Minnesota ranged from \$39 to \$96 per year, while mean existence value estimates ranged from \$68 to \$119 per year (1985 U.S. dollars). Estimates of median willingness to accept compensation for losses due to severe effects of acid deposition ranged from \$1,812 to \$1,814 per year. The aggregate benefits for the adult population of Minnesota due to preventing severe effects of acid deposition in Minnesota lakes and streams was estimated to be \$169 million per year. Control costs within the state of Minnesota were subtracted from aggregate benefits to determine the net benefit of protecting threatened lakes and streams in the state from severe effects of acid deposition. The results yielded a lower bound estimate of net benefits equal to \$124 million per year.	**USA**
4.5 METHANE	Species Loss and/or Decline; Habitat Loss or Degradation; Crop Productivity; Water Quality Decline; Human Health; Property Values; Public Complaints; Refugee Crisis	*See 4.1.1.*	-
4.6 VOLATILE ORGANIC ACIDS	Species Loss and/or Decline; Habitat Loss or Degradation; Crop Productivity; Water Quality Decline; Human Health; Property Values; Public Complaints; Refugee Crisis	*See 4.8.*	-
4.7 CHLOROFLUORO/B	Species Loss and/or Decline; Habitat Loss or Degradation; Crop	**4.7.1 Murdoch, J.C., and M.A. Thayer, "The Benefits of Reducing the Incidence of Nonmelanoma Skin Cancers: A Defensive Expenditures Approach", Journal of Environmental Economics**	**USA**

ROMO CARBONS & HALONS	Productivity; Water Quality Decline; Human Health; Property Values; Public Complaints; Refugee Crisis	**and Management 18, no. 2, 107-119 , 1990.** This study uses a defensive expenditures approach to estimate the benefits of ozone preservation through the year 2050. The baseline level of provision is the 1985 ozone level and the corresponding UV-b level. Six alternate levels are valued, including: a 0.74 percent increase in UV-b radiation in the year 2000, a 1.71 percent increase in 2010, a 3.51 percent increase in 2020, a 6.32 percent increase in 2030; a 10.35 percent increase in 2040, and a 17.05 percent increase in 2050. Deterioration of the ozone layer potentially affects human health through increased skin cancer rates. The results from the defensive expenditures approach are compared with estimates generated using a cost of illness (COI) approach. Defensive expenditures are measured as the change in purchase of sun protection products (due to an increase in UV-b radiation). Estimated present value of defensive expenditures range from $95.68 billion for a 0.74 percent increase in UV-b radiation exposure in 2000 to $197.79 billion for a 17.05 percent increase in UV-b radiation in 2050. COI estimates are estimated by multiplying the expected increase in nonmelanoma skin cancer cases by the estimated cost of treatment, and valuing deaths at $3 million each. COI estimates are about two times greater than the estimated defensive expenditures. The results imply that the use of COI to assess policy alternatives may lead to incorrect policy decisions.	
		4.7.2 Dickie, M. and S. Gerking, "Formation of Risk Beliefs, Joint Production and Willingness to Pay to Avoid Skin Cancer", The Review of Economics and Statistics 78, no. 3, 751-763 , 1996. This study uses an in-person survey of households in Laramie, Wyoming and San Diego, California to elicit a willingness to pay (WTP) to reduce skin cancer. These communities have a large number of sunny days and residents have experience dealing with the consequences of sunlight exposure, such as sun tanning, sun burning and increased skin cancer risk. A hypothetical sun protection lotion was used for the WTP scenario. A total of 291 individuals were surveyed for this study which was partially funded by the U.S. Environmental Protection Agency. Results from a WTP regression were used to compute option price estimates to reduce the risk of skin cancer for low, medium, and high income households with different levels of initial perceived risk of getting skin cancer. Option prices for a five percentage point reduction in risk ranged from $36.80 to $60.75 (1988 U.S. dollars). Multiplying option prices by 20 to obtain lifetime estimates to avoid skin cancer got a range from $720 to $1,200. These results were similar to another study on avoiding skin poisoning from insecticide but below the range of medical treatment costs for nonmelanoma cancer.	**USA**
		4.7.3 Dickie, M. and S. Gerking, "Willingness to Pay for Ozone Control: Inferences from the Demand for Medical Care", Journal of Environmental Economics and Management 21, no.1, 1-16 , 1991. The demand for medical services was estimated to calculate the consumer surplus (CS) associated with the control of ozone concentrations in the Los Angeles area. The change in demand for medical services associated with ozone control was used to estimate the change in medical expenditures (CME) due to ozone control. An in-person interview and multiple telephone interviews were administered to a sample of 226 residents of Glendora and Burbank, California. Annual CS estimates per person ranged from $115 in Burbank for peak ozone concentrations that never exceed 12 parts per hundred million (pphm) to $314 in Glendora for concentrations that never exceed 9 pphm (1985 U.S. dollars). The CME associated with ozone control ranged from $25 in Burbank for a 9 pphm peak to $148 in Glendora for a 12 pphm peak. The CS values were found to be two to four times greater than the CME values. This research was funded in part by the U.S. Environmental Protection Agency.	**USA**
4.8 PARTICULATES	Species Loss and/or Decline; Habitat Loss or Degradation; Human Health	**4.7.4 Cifuentes, L.A., and L.B. Lave, "Economic Valuation of Air Pollution Abatement: Benefits from Health Effects", Annual Review of Energy and the Environment 18, no. 1, 319-342, 1993.** This study reviewed several other health effects and health valuation studies to derive marginal benefits of emissions reductions of air pollutants such as particulate matter, sulphur oxides, nitrogen oxides, volatile organic compounds, and ozone. Some of the mortality and morbidity health studies consulted included Fisher et al. (1989); Viscusi (1988); Loehman et al. (1979); Krupnick and Kopp (1988); and Lave and Seskin (1977). Data on national pollutant emissions were obtained from the U.S. Environmental Protection Agency. Depending on the pollutant, marginal pollutant benefits ranged from $287 to $1,146 per	**USA**

		ton of pollutant emissions reduced (1991 U.S. dollars): Low Estimate: Mortality Particulates: $579; Morbidity Particulates: $343; Sulphate: $287; Morbidity Ozone (VOCs) $77; Morbidity Ozone (Nitrogen dioxide) $96. High Estimate: Mortality Particulates: $2,315; Morbidity Particulates: $845; Sulphate: $1,146; Morbidity Ozone (VOCs) $234; Morbidity Ozone (Nitrogen dioxide) $290.	
5 SOCIETY			
5.1 ENHANCEMENT	Addition of Species; Habitat Enhancement	**5.1.1. Hayes, Karen M., Timothy J. Tyrrell, and Glen Anderson., "Estimating the Benefits of Water Quality Improvements in the Upper Narragansett Bay.", Marine Resource Economics, Vol. (7), pp. 75-85, 1992.** The purpose of this study was to estimate the annual aggregate benefits of improving the water quality in Upper Narragansett Bay to Rhode Island residents. The study evaluates willingness to pay for improvements in water quality using a discrete choice contingent valuation survey. The study estimates that improved water quality would generate benefits of $30 - $60 million annually from swimming, and $30 - $70 million annually from shellfishing. According to the study, the values depends on the type of measure estimated (mean or median), and the survey format administered. WTP measures also depend on the type of reduction in pollutant offered, and whether the water quality improvement would make water safe enough for swimming, shellfishing, or both. Ignoring payment vehicle bias, the study confirms that no significant measure of bias were evident following tests on "willingness to pay" questions and their corresponding mean and median values.	**USA**
5.2 SOCIAL COSTS	Crime Levels	**5.2.1. Lindberg, K.A., "Assessment of Tourism's Social Impacts in Oregon Coast Communities Using Contingent Valuation, Value-Attitude, and Expectancy-Value Models", Dissertation, Oregon State University, 1997.** Willingness to pay (WTP) of residents of eight coastal Oregon communities for a reduction in tourism impacts was elicited using a dichotomous choice contingent valuation method. The social impacts of tourism development along the Oregon coast include traffic congestion, noise and minor crime violations, and demand for low-income housing. A telephone and mail survey administered in 1993 was used to elicit WTP for a 30 percent reduction in noise, a 25 or 50 percent reduction in congestion, and for provision of low-income housing. Mean annual household WTP when protest bids are excluded or converted was $101 for congestion reduction, $105 for noise and minor crime reduction, and $116 for low-income housing (1993 U.S. dollars). The Sea Grant and Coastal Oregon Productivity Enhancement Program sponsored the survey.	**USA**
		5.2.2. Lindberg, Kreg., Rebecca L. Johnson, and Robert P. Berrens., "Contingent Valuation of Rural Tourism Development With Tests of Scope and Mode Stability", Journal of Agricultural and Resource Economics, Vol. (22), 1, pp. 44-60, 1997. This study administers a dichotomous choice referendum style survey to 8 communities in rural Oregon to determine willingness to pay measures for 3 programs offering reduction in negative socio-physical impacts occurring from increased tourism in the area of these communities. The study estimates that annual household willingness to pay to reduce traffic congestion, for example, is $186 and for reduced noise and minor crime is $130. The programs offered are aimed at reducing traffic congestion, noise, and crime. The study includes tests of sensitivity in scope of the survey, and stability across survey modes (telephone v. mail). The study concludes that there is no evidence of scope effects, but that conclusions regarding sensitivity to scope depend on the kind of test used. The study suggests further that willingness to pay estimates for the programs offered are less in mail surveys relative to WTP estimates generated by the telephone survey mode. Values are in 1993 US dollars.	**USA**